April 2014

DIN EN 1012-3

ICS 23.140; 23.160

Compressors and vacuum pumps – Safety requirements – Part 3: Process compressors; English version EN 1012-3:2013, English translation of DIN EN 1012-3:2014-04

Kompressoren und Vakuumpumpen –
Sicherheitsanforderungen –
Teil 3: Prozesskompressoren;
Englische Fassung EN 1012-3:2013,
Englische Übersetzung von DIN EN 1012-3:2014-04

Compresseurs et pompes à vide –
Prescriptions de sécurité –
Partie 3: Compresseurs de procédé;
Version anglaise EN 1012-3:2013,
Traduction anglaise de DIN EN 1012-3:2014-04

Document comprises 107 pages

Translation by DIN-Sprachendienst.

In case of doubt, the German-language original shall be considered authoritative.

www.din.de
www.beuth.de

03.14 2140979

A comma is used as the decimal marker.

National foreword

This standard includes safety requirements.

This document (EN 1012-3:2013) has been prepared by Technical Committee CEN/TC 232 “Compressors, vacuum pumps” (Secretariat: UNI, Italy).

The responsible German body involved in its preparation was the *Normenausschuss Maschinenbau* (Mechanical Engineering Standards Committee), Working Committee NA 060-08-11 AA *Prozessgaskompressoren* of Section *Kompressoren und Drucklufttechnik*. Representatives of manufacturers and users of compressors, and of the employers’ liability insurance associations contributed to this standard.

This standard contains specifications meeting the essential requirements set out in Annex I of the “Machinery Directive”, Directive 2006/42/EC, and which apply to machines that are either first placed on the market or commissioned within the EEA. This standard serves to facilitate proof of compliance with the essential requirements of that directive.

Once this standard is cited in the Official Journal of the European Union, it is deemed a “harmonized” standard and thus, a manufacturer applying this standard may assume compliance with the requirements of the Machinery Directive (“presumption of conformity”).

The European Standards referred to in Clause 2 and in the Bibliography of the EN have been published as the corresponding DIN EN or DIN EN ISO Standards with the same number.

Where the International Standards referred to are not also DIN ISO Standards with the same number, there are no national standards available.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1012-3

November 2013

ICS 23.140; 23.160

English Version

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Kompressoren und Vakuumpumpen - Sicherheitsanforderungen - Teil 3: Prozesskompressoren

This European Standard was approved by CEN on 8 September 2013.

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Ref. No. EN 1012-3:2013 E

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Foreword

This document (EN 1012-3:2013) has been prepared by Technical Committee CEN/TC 232 “Compressors, vacuum pumps and their systems”, the secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2014, and conflicting national standards shall be withdrawn at the latest by May 2014.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

EN 1012, *Compressors and vacuum pumps*, is composed of the following parts:

— *Part 1: Air compressors*;

— *Part 2: Vacuum pumps*;

— *Part 3: Process compressors* (the present document).

The responsibility of CEN/TC 232 includes coordination of safety standards with CEN/TC 182, Refrigerating systems, safety and environmental requirements, and CEN/TC 234, Gas infrastructure.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

This document is a type C standard as stated in EN ISO 12100.

The machinery concerned and the extent to which hazards, hazardous situations and events are covered are indicated in the scope of this document.

When provisions of this type C standard are different from those which are stated in type A and B standards, the provisions of this type C standard take precedence over the provisions of the other standards for machines that have been designed and built according to the provisions of this type C standard.

When published in 1996, Part 1 of EN 1012 applied to all types of compressor. The standard is now divided into 3 parts with Part 1 addressing compressors for compressed air, nitrogen and inert gases and Part 3 addressing compressors for process gases. Part 2 continues to address vacuum pumps.

Separating requirements for process gas compressors from those for compressors for air, nitrogen and other inert gases was considered a practical move so that the requirements for one type of compressor could be changed without affecting the complete standard.

Where texts parts of EN 1012-3 are identical with EN 1012-1:2010, these are identified and formatted in italics.

If common requirements for functional safety would be applied to all process compressors, the variety in the application of process compressors may cause significantly different levels of residual risk. Therefore, in addition to the requirements of this standard, the application of risk assessment may be required for safety related control systems in the case of particular applications to specify performance levels and/or safety integrity levels for related aspects of functional safety.

Informative Annex C has been included to provide guidance on risk assessment for related aspects of functional safety, including the determination of safety integrity levels and/or performance levels. The manufacturer of the compressor is responsible for carrying out such a risk assessment and applying appropriate preventive measures. These tasks are outside the scope of this standard.

1 Scope

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 manufacturer (see Clause 4).

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.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 626-1:1994+A1:2008, *Safety of machinery — Reduction of risks to health from hazardous substances emitted by machinery — Part 1: Principles and specifications for machinery manufacturers*

EN 764-7:2002, *Pressure equipment — Part 7: Safety systems for unfired pressure equipment*

EN 837-2, *Pressure gauges — Part 2: Selection and installation recommendations for pressure gauges*

EN 953:1997+A1:2009, *Safety of machinery — Guards — General requirements for the design and construction of fixed and movable guards*

EN 1005-2, *Safety of machinery — Human physical performance — Part 2: Manual handling of machinery and component parts of machinery*

EN 1005-3, *Safety of machinery — Human physical performance — Part 3: Recommended force limits for machinery operation*

EN 1127-1, *Explosive atmospheres — Explosion prevention and protection — Part 1: Basic concepts and methodology*

EN 12021, *Respiratory protective devices — Compressed air for breathing apparatus*

EN 12195-1, *Load restraining on road vehicles — Safety — Part 1: Calculation of securing forces*

EN 13001-2, *Crane safety — General design — Part 2: Load actions*

EN 13155, *Cranes — Safety — Non-fixed load lifting attachments*

EN 13309, *Construction machinery — Electromagnetic compatibility of machines with internal power supply*

EN 13445-5:2009, *Unfired pressure vessels — Part 5: Inspection and testing*

EN 13445-6, *Unfired pressure vessels — Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron*

EN 13463-1, *Non-electrical equipment for use in potentially explosive atmospheres — Part 1: Basic method and requirements*

EN 15198, *Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres*

EN 60079-0, *Explosive atmospheres — Part 0: Equipment — General requirements (IEC 60079-0:2011, modified)*

EN 60079-1, *Explosive atmospheres — Part 1: Equipment protection by flameproof enclosures "d" (IEC 60079-1)*

EN 60079-14, *Explosive atmospheres — Part 14: Electrical installations design, selection and erection (IEC 60079-14)*

EN 60204-1:2006[1)], *Safety of machinery — Electrical equipment of machines — Part 1: General requirements (IEC 60204-1:2005, modified)*

EN 60204-11, *Safety of machinery — Electrical equipment of machines — Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV (IEC 60204-11)*

EN 61000-6-2, *Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity for industrial environments (IEC 61000-6-2)*

EN 61000-6-4, *Electromagnetic compatibility (EMC) — Part 6-4: Generic standards — Emission standard for industrial environments (IEC 61000-6-4)*

EN 61310-2:2008, *Safety of machinery — Indication, marking and actuation — Part 2: Requirements for marking (IEC 61310-2:2007)*

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1) EN 60204-1:2006 is impacted by the stand-alone amendment EN 60204-1:2006/A1:2009 (IEC 60204-1:2005/A1:2008).

EN 61508-1:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 1: General requirements (IEC 61508-1:2010)*

EN 61508-2:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems (IEC 61508-2:2010)*

EN 61508-3, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 3: Software requirements (IEC 61508-3)*

EN 61508-4, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 4: Definitions and abbreviations (IEC 61508-4)*

EN 61508-5, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 5: Examples of methods for the determination of safety integrity levels (IEC 61508-5)*

EN 61508-6, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3 (IEC 61508-6)*

EN 61508-7, *Functional safety of electrical/electronic/programmable electronic safety-related systems — Part 7: Overview of techniques and measures (IEC 61508-7)*

EN 61511-1, *Functional safety — Safety instrumented systems for the process industry sector — Part 1: Framework, definitions, system, hardware and software requirements (IEC 61511-1)*

EN 61511-2, *Functional safety — Safety instrumented systems for the process industry sector — Part 2: Guidelines for the application of IEC 61511-1 (IEC 61511-2)*

EN 61511-3, *Functional safety — Safety instrumented systems for the process industry sector — Part 3: Guidance for the determination of the required safety integrity levels (IEC 61511-3)*

EN 62061, *Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems (IEC 62061)*

EN ISO 2151:2008, *Acoustics — Noise test code for compressors and vacuum pumps — Engineering method (Grade 2) (ISO 2151:2004)*

EN ISO 4126-1, *Safety devices for protection against excessive pressure — Part 1: Safety valves (ISO 4126-1)*

EN ISO 4413:2010, *Hydraulic fluid power — General rules and safety requirements for systems and their components (ISO 4413:2010)*

EN ISO 4414:2010, *Pneumatic fluid power — General rules and safety requirements for systems and their components (ISO 4414:2010)*

EN ISO 11688-1, *Acoustics — Recommended practice for the design of low-noise machinery and equipment — Part 1: Planning (ISO/TR 11688-1)*

EN ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction (ISO 12100:2010)*

EN ISO 13849-1:2008, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design (ISO 13849-1:2006)*

EN ISO 13850:2008, *Safety of machinery — Emergency stop — Principles for design (ISO 13850:2006)*

EN ISO 13857, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs (ISO 13857)*

EN ISO 14122-1, *Safety of machinery — Permanent means of access to machinery — Part 1: Choice of fixed means of access between two levels (ISO 14122-1)*

EN ISO 14122-2, *Safety of machinery — Permanent means of access to machinery — Part 2: Working platforms and walkways (ISO 14122-2)*

EN ISO 14122-3, *Safety of machinery — Permanent means of access to machinery — Part 3: Stairs, stepladders and guard-rails (ISO 14122-3)*

EN ISO 14122-4, *Safety of machinery — Permanent means of access to machinery — Part 4: Fixed ladders (ISO 14122-4)*

EN ISO 14163, *Acoustics — Guidelines for noise control by silencers (ISO 14163)*

EN ISO 15156-1, *Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials (ISO 15156-1)*

EN ISO 15667, *Acoustics — Guidelines for noise control by enclosures and cabins (ISO 15667)*

ISO 3857-1, *Compressors, pneumatic tools and machines — Vocabulary — Part 1: General*

ISO 3857-2, *Compressors, pneumatic tools and machines — Vocabulary — Part 2: Compressors*

ISO 8573-1, *Compressed air — Part 1: Contaminants and purity classes*

ISO 8573-2, *Compressed air — Part 2: Test methods for oil aerosol content*

ISO 8573-3, *Compressed air — Part 3: Test methods for measurement of humidity*

ISO 8573-4, *Compressed air — Part 4: Test methods for solid particle content*

IEC 60417 (2002-10), *Graphical symbols for use on equipment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100:2010 apply.

Definitions specifically needed for compressors are listed below and in the standards ISO 3857-1 and ISO 3857-2.

3.1 General terms

3.1.1
compressor
part of a compressor unit that compresses a gas or vapour media to a pressure higher than that at the inlet

3.1.2
compressor unit
unit that comprises the compressor, a drive system and any component or device which is necessary for operation

3.1.3
depressurisation
reduction of the pressure difference between the inside of a pressure containing part and its environment to zero

EXAMPLE Stopping a compressor may lead to higher pressures on the suction side. In such cases, achieving a safe state may include depressurizing.

3.1.4
drive system
system that consists of a prime mover and coupling mechanism

Note 1 to entry: Prime mover may be an electric motor, steam engine (turbine), etc.

Note 2 to entry: Coupling mechanism may be a drive belt, shaft, gears, etc.

3.1.5
harm
physical injury or damage to health

[SOURCE: EN ISO 12100:2010, definition 3.5]

3.1.6
hazard
potential source of harm

[SOURCE: EN ISO 12100:2010, definition 3.6]

3.1.6.1
hazard zone
danger zone
space within and/or around machinery in which a person can be exposed to a hazard

[SOURCE: EN ISO 12100:2010, definition 3.11]

3.1.6.2
hazardous event
event that can cause harm

Note 1 to entry: A hazardous event can occur over a short period of time or over an extended period of time.

3.1.6.3
hazardous situation
circumstance in which a person is exposed to at least one hazard

Note 1 to entry: The exposure can result in harm immediately or over a period of time.

[SOURCE: EN ISO 12100:2010, definition 3.10]

3.1.6.4
hazardous gas or vapour
gas or vapour with chemical, radioactive or biological properties (such as flammable, explosive, unstable, pyrogenic, corrosive, caustic, toxic, carcinogenic), which generate hazards by reactions inside the compressor or through dispersal or through reactions with the environment

Note 1 to entry: A hazardous gas may be a mixture of gases with these properties.

3.1.7
inert gases
chemically inactive gas which retains this characteristic even at elevated pressures and temperatures

3.1.8
liquid shock
excessive force resulting from an attempt to compress incompressible media

3.1.9
maximum allowable pressure
maximum allowable working pressure
maximum pressure for which the compressor or compressor unit is designed, as specified by the manufacturer

3.1.10
maximum allowable temperature
maximum allowable working temperature
maximum operating temperature, as specified by the manufacturer

3.1.11
maximum continuous shaft speed
highest rotational speed at which the compressor at any of the specified operating conditions is capable of continuous operation

Note 1 to entry: The maximum continuous speed is specified by the manufacturer.

3.1.12
nominal discharge pressure
rated discharge pressure
pressure at the outlet of the compressor, as specified by the manufacturer

3.1.13
normal operating conditions
conditions considered to be when the compressor is properly maintained and operated within admissible limits in particular ambient temperature, as specified by the manufacturer compressing the specified media

3.1.14
pressure
pressure relative to atmospheric pressure, i.e. gauge pressure

Note 1 to entry: In many cases, this is referred to as effective pressure.

Note 2 to entry: The unit bar for pressure is used. 1 bar = 100 kPa.

3.1.15
rated power
maximum permitted power (mechanical or electrical)

Note 1 to entry: Nominal power is a synonym for rated power.

3.1.16
risk
combination of the probability of occurrence of harm and the severity of that harm

[SOURCE: EN ISO 12100:2010, definition 3.12]

3.1.17
residual risk
risk remaining after protective measures have been taken

Note 1 to entry: See EN ISO 12100:2010, Figure 2.

[SOURCE: EN ISO 12100:2010, definition 3.17]

3.1.18
safety function
function of the machine whose failure can result in an immediate increase of the risk(s)

[SOURCE: EN ISO 12100:2010, 3.30; EN ISO 13849-1:2008, 3.1.20]

3.1.19
safety related control
safety instrumented system
SIS
control device that carries out one or more safety function(s)

Note 1 to entry: This definition corresponds to safety instrumented system (SIS) according to EN 61511-1.

3.1.20
shutdown
stopping of all prime movers of a compressor

3.1.20.1
automatic shutdown
automatically initiated stopping of a compressor initiated by limiting device or safety device

Note 1 to entry: Automatic shutdown is commonly denoted as “tripping”.

Note 2 to entry: This definition describes the way of initiating a normal, safety related controlled or emergency shutdown.

3.1.20.2
normal shutdown
manually or automatically initiated stopping of a compressor which may include full sequential actuation of auxiliary equipment and drive system

3.1.20.3
safety related controlled shutdown
manually or automatically initiated stopping of a compressor which includes a reduced (compared to normal shutdown) sequential actuation of auxiliary equipment and drive system

Note 1 to entry: This type of shutdown is initiated by a safety related function.

Note 2 to entry: Reduced sequential actuation means a reduced number and/or duration of steps of the sequence.

Note 3 to entry: After a normal shutdown the energy to the prime movers can be cut off or not (see stop category 1 or 2 of 9.2.2 of EN 60204-1:2006).

Note 4 to entry: Manually initiated stopping of a compressor which includes a reduced (compared to normal shutdown) sequential actuation of auxiliary equipment and drive system is often denoted as emergency stop.

3.1.20.4
emergency shutdown
manually or automatically initiated stopping of a compressor with immediate cut of the energy to the prime mover

Note 1 to entry: This type of shutdown is initiated by a safety related function.

Note 2 to entry: This shutdown definition is related to the stop category 0 of 9.2.2 of EN 60204-1:2006.

3.1.21
unexpected start-up
unintended start-up
start-up which, because of its unexpected nature, generates a hazard by, for example:

— a start command which is the result of a failure in, or an external influence on, the control system;

— a start command generated by inopportune action on a start control or other parts of the machine as, e.g., a sensor or a power control element;

— restoration of the power supply after an interruption;

— external / internal influences (e.g. gravity, wind, self-ignition in internal combustion engines) on parts of the machine.

Note 1 to entry: Machine start-up during the normal sequence of an automatic cycle is not unintended, but can be considered to be unexpected from the point of view of the operator. Prevention of accidents in this case involves the use of safeguarding measures (see EN ISO 12100-2:2010, Clause 5).

[SOURCE: EN ISO 12100:2010, 3.31]

3.2 Specific terms

3.2.1
acetylene compressor
compressor intended for handling technically pure acetylene

Note 1 to entry: For mixtures of acetylene with other gases or liquids the applicability of the relevant acetylene specifications will be decided on a case by case basis.

3.2.2
air compressor
compressor intended for compression of air, nitrogen or inert gases

3.2.3
auxiliary energy supply
energy which forces auxiliary systems (e.g. oil systems, cooling system or valves) to operate

3.2.4
compressor assembly
assembly of compressor units and ancillary equipment to provide a compression facility that functions as an integrated whole

Note 1 to entry: The limits of the assembly are as defined by the manufacturer.

3.2.5
control energy supply
energy supply for the control system (e.g. control voltage)

3.2.6
high pressure compressor
compressor for maximum allowable working pressures above 50 bar

3.2.7
large compressor
compressor with an input shaft power above 1 000 kW

3.2.8
low temperature compressor
compressor for continuous handling of media other than air, inert gases or nitrogen, having an inlet temperature below 0 °C

3.2.9
main energy supply
energy which forces the prime mover(s) of the compressor to turn

3.2.10
oil-flooded compressor
compressor design in which the compressed gas or vapour and the oil are mixed

Note 1 to entry: In such compressors, a considerable amount of oil is injected into the gas or vapour in order to reduce the gas discharge temperature.

3.2.11
oil-free compressor
compressor design in which the compressed gas or vapour does not come in contact with oil

3.2.12
oil-lubricated compressor
compressor design in which the compressed gas or vapour may come in contact with oil but excluding oil-flooded compressors

3.2.13
oxygen compressor
compressor for handling pure oxygen or oxygen rich mixture, of more than 70 mole percent oxygen

Note 1 to entry: If ideal gas law is applicable mole fraction is equivalent to volume fraction.

3.2.14
portable and skid-mounted compressor

3.2.14.1
portable compressor unit
compressor unit which is wheel-mounted and can be towed on and off-site

3.2.14.2
skid-mounted compressor unit
compressor unit which is mounted on skids and which is intended to be towed short distances on-site or transported on-site

3.2.14.3
gross mass
maximum specified mass of the skid mounted or portable compressor unit (including tools, equipment and fuel)

Note 1 to entry: Tools and equipment includes for example concrete breakers, picks and hoses likely to be carried for a typical working application.

3.2.15
process (gas) compressor
compressor intended for compression of all gases other than air, nitrogen or other inert gases

3.2.16
water-injected compressor
compressor design in which the compressed gas and the water are mixed

4 List of significant hazards – Hazard analysis and risk assessment

The hazards listed in Table 1 have been identified by risk assessment as applicable and are related to all compressors/compressor units within the scope of this European Standard.

NOTE Basis of the risk assessment is EN ISO 12100.

Table 1 — Hazard listing

No.	Hazard type	Reference to safety requirement	
		By design or guarding	Information for use
1	**Mechanical hazards due to:**		
1.1	Rotating or moving elements resulting in — crushing — shearing — drawing-in, trapping or entanglement	5.2.2.1 5.2.2.2 5.2.2.3	
1.2	Shape (e.g. sharp edges) and/or superficial finishing of accessible parts of the machine in: — contact with rough surfaces — contact with sharp edges and corners, protruding parts resulting in: — cutting or severing — friction or abrasion	5.2.1 5.2.2.2	7.2.1.6 q), 7.2.1.7 a)
1.3	Ejection of parts resulting in: — crushing — being hit / being thrown / being gripped	5.2.2.4	
1.4	Instability of parts or components resulting in: — crushing — cutting — impact	5.2.4	7.2.1.11a) and d) 7.3.3 i)
1.5	Loss of stability / overturning of machinery as a result of: — geometry of base — weight distribution — oscillation of the centre of gravity — external forces (e.g. wind pressure, manual forces)	5.2.4, 5.2.5, 5.2.5.8	7.2.1.4 7.3.3 i) 7.2.1.11 a) and d) 7.2.1.6
1.6	High pressure injection or ejection resulting in: — displacement of moving elements — ejection of high pressure fluids — uncontrolled movements	5.2.3 5.10.6.2 5.11	7.2.1.6 r)

Table 1 (*2 of 6*)

No.	Hazard type	Reference to safety requirement	
		By design or guarding	Information for use
1.7	High pressure (stored energy) resulting in: a) bursting 1) ejection of pressure containing parts or particles 2) being thrown b) escape of hazardous fluids 1) poisoning 2) suffocation 3) burn	5.4.6.3, 5.8.3, 5.8.4, 5.10.1, 5.10.3, 5.10.6.1, 5.10.6.2 5.11 5.12	7.2.1.6 d), e), i), k), m), 7.2.1.11 b), c), 7.2.1.7 0 7.3.4.1 f)
1.8	Stored energy (kinetic or potential energy) of the machine, parts of the machine, tools and materials used or elastic elements resulting in: — being thrown — crushing — shearing	5.10.3	7.2.2.2
2	**Electrical hazards due to:**		
2.1	Contact of persons with electrical equipment parts or live parts (direct contact) or electrical equipment parts which become live under fault conditions (indirect contact) — shock — electrocution — falling, being thrown — burn — fire	5.3	7.2.1.5.1, 7.2.1.5.2 7.2.2.2
2.2	External influences on the electrical equipment e.g.: — short-circuit — overload — electromagnetic phenomena — interruptions or variations in the supply voltage — earthing faults causing fire, burn, chemical effects	5.3; 5.4.5.3	7.2.1.5.1

Table 1 (*3 of 6*)

No.	Hazard type	Reference to safety requirement	
		By design or guarding	**Information for use**
2.3	Electrostatic phenomena resulting in: — shock — electrocution — uncontrolled motion, e.g. falling because of being scared	5.8.2	7.2.2.2
2.4	Electromagnetic phenomena resulting in: — effects on medical implants — malfunction of electrical equipment of the compressor / compressor unit due to lack of EMC- immunity (surge immunity) — effects on other electrical equipment due to EMC emissions from the compressor / compressor unit	5.4.5.4	
3	**Thermal hazards due to**		
3.1	Contact of persons with objects or materials with extremely high or low temperature resulting in: — burns — scalds — other injuries	5.5	7.2.1.7 e) 7.3.2
4	**Hazards due to noise**		
4.1	Noise: — hearing loss (deafness), tinnitus — stress, tiredness — other physiological disorders (e.g. loss of balance, loss of awareness) — accidents due to impairment of speech communication or of the perception of acoustic signals	5.6	7.2.1.10,
5	**Several hazards due to materials and substances processed or used:**		
5.1	Breathing or contact with the materials and substances processed or used, resulting in: — breathing difficulties, suffocation — impairment of health (e.g. poisoning)	5.7.1, 5.7.2, 5.7.3, 5.7.4, 5.7.5, 5.7.6, 5.7.7, 5.7.8, 5.7.9	7.2.1.7h), 7.2.1.7f), 7.2.2.1, 7.2.2.2,

Table 1 (*4 of 6*)

No.	**Hazard type**	**Reference to safety requirement**	
		By design or guarding	**Information for use**
5.2	Fire and/or explosion hazards	5.8	7.2.1.6 o) and p) 7.2.1.7g) and o)
5.3	Biological or microbiological (e.g. viral or bacterial) hazards, resulting in: — breathing difficulties, suffocation — impairment of health (e.g. poisoning)	5.7.10	7.2.1.7 i), j) and k) 7.2.1.7 f) and 7.2.1.11 e)
6	**Hazards due to neglecting ergonomic principles in machinery design:**		
6.1	Poor visibility and/or readability and/or accessibility of indicators and visual displays	5.9	
6.2	Poor accessibility of access closures and other machine areas that have to be accessed for routine maintenance	5.2.2.5	7.2.2.2
7	**Hazards due to the environment in which the machine is used, e.g. hazards created by operating the compressor/compressor unit in:**		7.2.1.8 f)
7.1	Environmental conditions, e.g. dusty air or polluted air or moist air, temperature and ambient pressure		7.2.1.8 c)
7.2	Loads created by snow, wind and earthquake: — hazard resulting from breaking down of machinery parts and other functional disorders	5.10.2	7.2.1.6
7.3	Low temperature	5.10.4	7.2.1.6 b), c), i) and m)
7.4	Hazards created by lightning	5.3.4	7.2.1.5.5
8	**Hazards due to an unexpected start/restart caused by:**		
8.1	Failure/disorder of the control system	5.4.3, 5.4.4, 5.4.5, 5.4.5.1, 5.4.5.2; 5.4.5.3	7.2.1.7 c) and d) 7.2.1.9 h), 7.2.1.9 d)
8.2	Restoration of the power supply after a long term electric power interruption	5.2.8	7.2.1.5.2, 7.2.1.7c) and d) 7.2.2.1
9	**Hazard due to loss of main energy/power supply or short term interruption:**		
9.1	– reverse running of the compressor – higher settle out pressure	5.2.9	

Table 1 (*5 of 6*)

No.	Hazard type	Reference to safety requirement	
		By design or guarding	**Information for use**
10	**Hazards due to breaking down of machinery parts and other functional disorders caused by:**		
10.1	Improper material properties, e.g. deficient ductility and fatigue resistance: — displacement of moving elements — uncontrolled movements — bursting — escape of hazardous fluids — ejection of pressure containing parts or particles	5.10.3	
10.2	Incompatibility of materials used with the lubricants or other fluids used and with the gases being processed	5.10.3	7.2.1.6 g), h), i), m), n), o), p), 7.2.2.2
10.3	Liquid shock	5.10.5	7.2.1.7 l)
10.4	Overstressing of integral pipework, hoses and auxiliaries	5.2.3	7.2.1.6 r)
10.5	Overstressing of power transmission element, e.g. coupling, gear, shaft	5.10.3	
10.6	Underspeed /overspeed /critical speed	5.2.7	7.2.1.7 n)
10.7	Exceeding temperature of the process	5.5, 5.7.2, 5.7.3, 5.7.4, 5.8.1, 5.8.3, 5.8.4, 5.10.1, 5.10.7, 5.10.8	7.2.1.6 c), 7.2.2.2
10.8	Failure of shaft seals system	5.7.8	
10.9	Surge of a turbo compressor	5.10.3, 5.10.9	
10.10	Axial displacement of shaft	5.10.3	
10.11	Reverse running	5.2.9	
11	**Hazards due to access to hazardous areas, e.g.:**		
11.1	— mechanical hazards, e.g. crushing, shearing, drawing-in, trapping or entanglement — breathing difficulties, suffocation, impairment of health, poisoning — getting/being trapped	5.2.2.5, 5.7.7	7.2.1.6 q), 7.2.2.1, 7.2.2.2
12	**Hazard due to lifting and transportation**		
12.1	— e.g. crushing, loss of stability	5.2.4, 5.2.5, 5.2.5.8	7.2.1.4

Table 1 (*6 of 6*)

No.	Hazard type	Reference to safety requirement	
		By design or guarding	Information for use
13	**Hazard due to slip, trip and fall of persons (related to machinery)**	5.2.6	
14	**Hazards due to insufficient information for use**		7
15	**Additional hazards from portable compressors**		
15.1	Exhaust gases/lack of oxygen/toxic gases at the work position		7.2.1.8 f), h), 7.2.1.11 e)
15.2	Noise at the operator's position	6.5	7.2.1.10,
15.3	From handling the machine (lack of stability)	5.2.5.8, 5.9.2	7.2.1.11 d)
15.4	Hazards from the engine and the batteries	5.3.5.2	
15.5	Hazards from coupling and towing	5.2.5.8, 5.9.3	7.2.1.11 a), f)
15.6	Lack or inadequacy of visual or acoustic warning means		7.3.3
15.7	Unhealthy postures or excessive effort	5.9.3	

5 Safety requirements and/or protective measures

5.1 General

Machinery shall comply with the safety requirements and/or protective measures of this clause. In addition, the machine shall be designed according to the principles of EN ISO 12100 for relevant but not significant hazards, which are not dealt with by this document.

When choice is necessary for the application of type B standards referred to in this European Standard, such as EN 60204-1, EN ISO 4414, EN 953 and others listed in Clause 2 of this standard and the specific measures are not identified in this clause, the manufacturer shall carry out an appropriate risk assessment for making these decisions.

This risk assessment according to EN ISO 12100, which is required because of the variability of the machinery involved, should be part of the general risk assessment that a manufacturer should carry out to identify and deal with any hazards not covered by this standard (see Introduction). When this standard does not fully cover a particular hazard, identified as significant by the risk assessment carried out by the manufacturer, so far as practicable associated risks should be reduced by the principle of inherently safe design. When the remaining risk is not tolerable, risk should be reduced by the application of protective devices. If such protective devices rely on safety related control systems, EN ISO 13849-1, EN 62061, EN 61508 or EN 61511 should be applied as appropriate. For the application of these standards to process gas compressors / compressor units, see Annex C of this standard for guidance and examples. If the risk cannot be reduced to a tolerable level (see the risk graph given in Annex C, Figure C.4) by such measures, information on the procedures required to control the residual risk should be established and documented. The specification of the additional measures referred to in this paragraph are not within the scope of this standard and are the responsibility of the compressor or compressor unit manufacturer.

The measures adopted to comply with the requirements of this clause shall take account of the state-of-the-art when more effective technical means become available.

Components used in the design and construction of process compressors shall comply with the requirements of appropriate standards. Such standards having a specific normative reference in this standard shall take precedence.

5.2 Mechanical safety

5.2.1 General

Outer shapes (e.g. sharp edges) of accessible parts of the machine which could lead to cutting, stabbing, etc. shall be avoided.

5.2.2 Guards

5.2.2.1 *General*

When fixed guards have to be removed for periodic maintenance their fixing systems shall remain attached to the guard or machinery when the guards are removed.

5.2.2.2 *Cutting and severing, friction and abrasion*

All moving parts shall be enclosed within the permanent compressor casing or compressor unit cover, enclosure or canopy. When this is not possible, separate guards shall be provided to prevent contact with all rotating and reciprocating parts to minimize the risk of cutting and severing, friction and abrasion to personnel in accordance with Clause 5 of EN 953:1997+A1:2009 and EN ISO 13857 for safety distances.

The term "moving parts" may include parts which are moving infrequently only under certain operating conditions.

5.2.2.3 *Bodily contact*

Guards shall be sufficiently rigid so as not to deflect excessively as a result of bodily contact. Such deflections shall not result in contact with moving parts, or that the deflection should not result in permanent deformation of the guard. The provisions for rigidity of guards shall be in accordance with 5.5.3 of EN 953:1997+A1:2009.

5.2.2.4 *Ejection of parts*

Moving parts shall be designed and mounted in such a way that in all foreseeable modes of operation the risk of ejection of parts is minimized. Where the risk assessment identifies a remaining risk of ejection, e.g. a drive belt from a belt driven compressor, then the impact resistance for guarding shall be in accordance with 5.5.2 of EN 953:1997+A1:2009.

If cooling inside a closed coupling guard is necessary, an appropriate cooling medium such as oil or nitrogen may be injected.

5.2.2.5 Openings in guards

Openings in guards, e.g. arising from the use of mesh, shall comply with the safe reach distances given in EN ISO 13857.

5.2.2.6 Access closures in guards

Access closures for inspection and maintenance activities, e.g. in acoustic hoods also providing a guarding function, flywheel enclosures, shall be in accordance with this clause and Clause 5 of EN 953:1997+A1:2009.

Where maintenance activities requiring access within the guarded areas are necessary whilst the compressor is still operational, consideration in accordance with 6.3.2.4 of EN ISO 12100:2010 shall be given to the additional hazards created.

Access closures can be divided into four types which shall have the following provisions:

a) Access closures large enough to enable whole body entry and that can be opened with tools or having a lock requiring a key, e.g. bolted elements or lockable doors of an acoustic hood also providing a guarding function:
The use of tools and locks to control access is acceptable if the expected frequency of entry is low. The guard provided for the opening shall be in accordance with 5.4.3 of EN 953:1997+A1:2009. Access closures of this type do not require additional design features. See 7.2.2.2 for information on procedures for controlling access to keys.

   Access closures large enough to enable whole body entry and that can be opened without tools or without a lock requiring a key, e.g. door with latch of an acoustic hood also providing a guarding function. The door provided for the opening shall be in accordance with 5.4.8 of EN 953:1997+A1:2009.
   Access closures of this type shall have provisions to automatically shutdown a running compressor before or when the guard is opened.
   The compressor shall be protected against unintentional start/restart according to 5.4.2 of this standard as long as the opening is open.

   An unintentional restart shall be avoided by e.g.:

   1) preventing the closing of the door when a person is inside, e.g. by means of a door that is lockable in the open position using a padlock. See 7.2.2.2 for warnings and information on procedures; or

   2) the door shall be openable from the inside and a compressor restart shall require the operation of a separate restart control before the starting procedure can commence.

b) Access closures large enough to enable access of body parts and that can be opened only with tools or having a lock requiring a key, e.g. bolted inspection cover in gear box casing:
The guard provided for the opening shall be in accordance with 5.4.3 of EN 953:1997+A1:2009. Access closures of this type do not require additional design features.

c) Access closures large enough to enable access of body parts and that can be opened without tools or without a lock requiring a key.
E.g. access closures in fly wheel guards required to provide access to timing marks, wheel hub and other parts which may require attention.
The guard provided for the opening shall be either a fixed or a self-closing guard. If this is not possible then the provisions of 7.2.1.6 q) of this standard shall be applied.

Generally, access frequency is understood as being "high" if it is more often than once per day.

5.2.3 Fluid injection

The risk of fluid (gas or liquid) injection into the human body shall be minimized by:

— *designing and supporting integral pipework, hoses and auxiliaries to withstand vibration, thermal expansion and their own mass, foreseeable external forces, influence of contaminants and external chemical substances;*

— *ensuring that all piping which is in a position likely to be damaged is protected, robust and sufficiently supported but shall be free to move with changing temperature;*

— *ensuring that the design of oil/coolant filler plugs does not allow the dangerous release of fluid, e.g. by means of preventing the removal of the filler plug under pressure or an effective warning system;*

— *the design and location of pressure vents and drains, shall take account of the velocity of air, gas, vapour or liquid likely to be discharged.*

5.2.4 Loss of stability

5.2.4.1 Generally applicable

Compressor units shall be in accordance with 6.2.6 of EN 12100:2010.

5.2.4.2 Portable and skid-mounted compressor units

The centre of gravity of the engine/compressor combination shall be sufficiently close to the supporting surface to ensure that the compressor remains stable, without tipping or slipping, when used within intended limits. The intended limits shall be specified in the instruction handbook supplied with the compressor (see 7.2.1.11 d)).

Tyres of a portable compressor shall be rated to carry the maximum gross mass of the portable compressor at the highest towing speed the compressor unit is intended for. All tyres shall be of the same construction.

The support leg or jockey wheel shall be capable of supporting the gross nose weight of the portable compressor unit as defined in the instruction handbook. It shall be possible to securely lock it in the support and towing positions by, for example, a clamping system or removable pin in locating holes.

The jockey wheel device shall be positively retained in the draw bar in the event of the operator leaving it unlocked.

NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

5.2.5 Lifting and transportation of compressor units and parts

5.2.5.1 General

When the lifting of a compressor or compressor unit is not possible without lifting points then these shall be provided. The design of lifting points shall be based on:

- load;
- positioning and number of lifting points;
- possible direction of the forces acting on the lifting points ;
- application of suitable safety factors.

5.2.5.2 Load

5.2.5.2.1 Static load

The static load (F_S) in N shall be the multiplication of the gravitational acceleration (g) in m/s^2 and the maximum mass (m) of the load in kg. That is:

$$F_s = m * g \qquad (1)$$

where

g = 9,81 m/s^2

5.2.5.2.2 Dynamic load

For the calculation of the dynamic load in order to account for acceleration during lifting a minimum dynamic factor of Φ_2 = 2,5 (worst case value according to EN 13001-2) shall be applied. The dynamic load (F_d) is the dynamic load factor times the static load (F_s). That is:

$$F_d = \phi_2 * F_s \tag{2}$$

If higher acceleration is foreseeable this shall be taken into account by adjusting Φ_2 in the calculation of the vertical dynamic load.

If the maximum dynamic load factor of the lifting equipment to be used is known to be lower than 2,5 (e.g. less than 2,5 when lifting devices are used at the limit of their lifting capacity) this can be used for the calculation of the dynamic load. In this case, the maximum allowable hoisting class and lifting velocity according to EN 13001-2 have to be stated in the manual and transportation documents (see 7.2.1.4). In addition, the same information has to be given in suitable signs mounted in the vicinity of the lifting points.

5.2.5.3 Positioning and number of lifting points

The following shall be taken into account when determining the position and number of lifting points:

a) In the case of rigid compressors or compressor units the number of lifting points to be used simultaneously shall not exceed 4.

b) The possible tilting of the load during lifting shall be avoided. Preferably the lifting points should be located above the centre of gravity of the load.

NOTE Locating the lifting points horizontally further away from the centre of gravity also reduces the risk of tilting.

c) The geometric position of the lifting points should be preferably symmetrical with respect to the centre of gravity of the compressor or the compressor unit and shall be in the same plane. In some cases unsymmetrical positioning of the lifting points in the same plane cannot be avoided. This result in the application of a potentially higher load to a particular lifting point or leg of lifting equipment and this shall be accounted for in the design and information supplied. The distribution of the load on the lifting points shall be taken to be as follows:

   1) One lifting point: the lifting point is exposed to the full load.

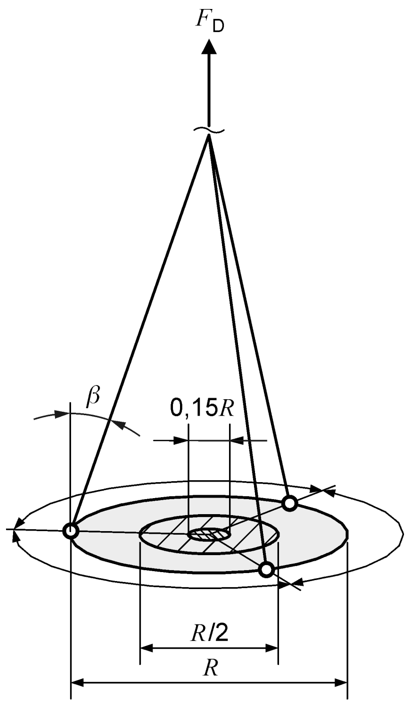
   2) Two lifting points: the load of each lifting point has to be determined according to the balance of moments.

   3) Three lifting points: the load of each lifting point has to be determined according to the balance of the moments and the forces. The vertical load on lifting points shall be determined in accordance with Figure 1 — which defines minimum values:

      i) Area where symmetrical position of centre of gravity of the load can be assumed:
      Vertical load on each lifting point = F_D/2,3;

      ii) Area where unsymmetrical position of centre of gravity of the load applies and where it can be assumed:
      Vertical load on each lifting point = F_D/1,5;

      iii) An individual analysis is required.



Key

o position of the lifting points

symmetrical position of centre of gravity: F_D/2,3

unsymmetrical position of centre of gravity: F_D/1,5

An individual analysis is necessary.

Figure 1 — Load distribution in the case of three lifting points

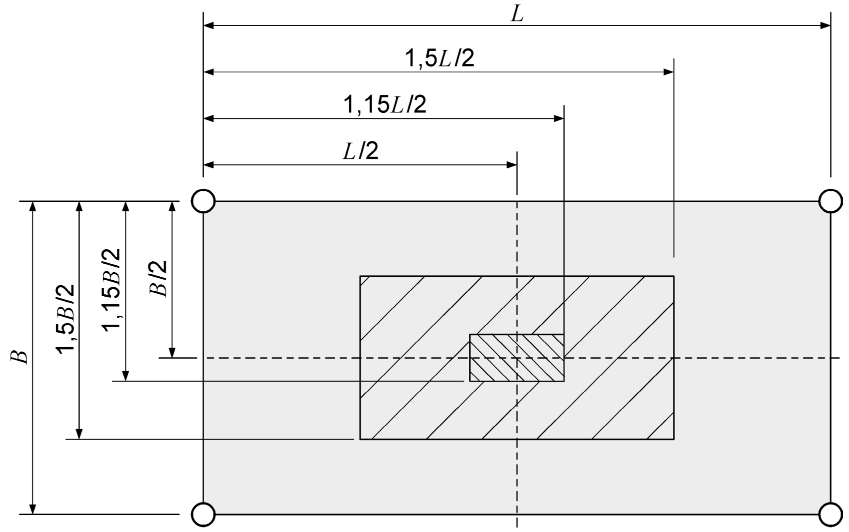
4) Four lifting points:

The load of each lifting point has to be determined according to the balance of the moments and the forces. The vertical load on lifting points shall be determined in accordance with Figure 2, which defines minimum values.

i) Area where symmetrical position of centre of gravity of the load can be assumed: Vertical load on each lifting point = FD/3;

ii) Area where unsymmetrical position of centre og gravity of the load applies and where it can be assumed:
Vertical load on each lifting point = FD/2;

iii) An individual analysis is required.



position of the lifting points

symmetrical position of centre of gravity: $F_D/3$

unsymmetrical position of centre of gravity: $F_D/2$

An individual analysis is necessary.

Figure 2 — Load distribution in the case of four lifting points

5) More than four lifting points: no general statement can be made. An individual analysis is required.

5.2.5.4 Influence of direction of the forces acting on the lifting points

The foreseeable direction of the forces acting on the lifting points (angle of inclination (β) between vertical and the lifting accessories, see Figure 3) shall be taken into account.

The angle ß affects the applied load with the load increasing as the angle ß increases. Under the normal use of lifting accessories the angle ß should not exceed 60°.

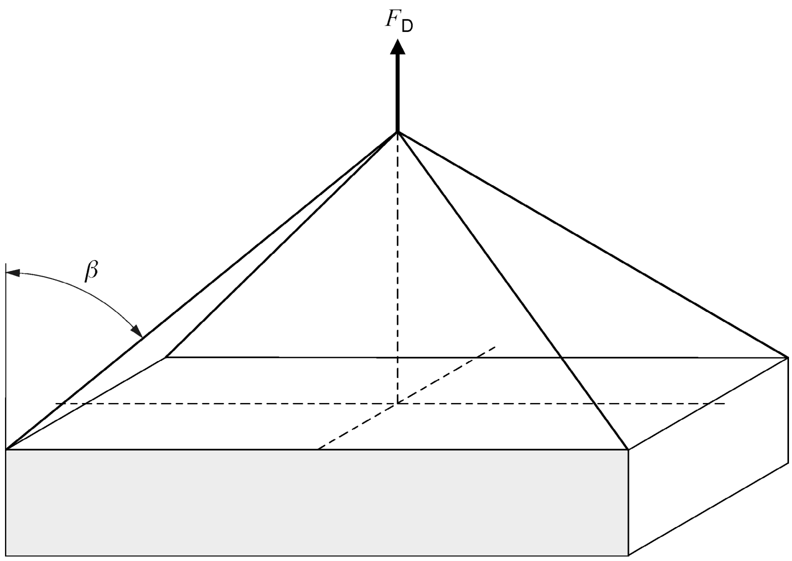


Figure 3 — Angle of inclination (β)

5.2.5.5 Safety factors

Lifting points shall be designed to withstand a load equal to the static safety factor (S_s)-times the static load. Lifting points shall be capable of bearing this load, however, permanent deformation or patent defect may occur.

The static safety-factor S_S equals:

- 4 for materials which are ductile at temperatures during lifting;
- 9 as a minimum for materials which are non-ductile at temperatures during lifting.

Lifting points shall be designed to withstand the dynamic load multiplied by S_D without permanent deformation.

The dynamic safety-factor S_D equals:

- 1,1 for materials which are ductile at temperatures during lifting;
- 9 as a minimum for materials which are non-ductile at temperatures during lifting.

5.2.5.6 Design consideration

In order to obtain a symmetrical load distribution in practice a minimum flexibility of the lifting devices is necessary. Uneven load distribution may occur by using very rigid lifting devices. This can be avoided by designing the lifting points (e.g. restricting size and shape of the lifting points) so that the use of lifting devices with excessive lifting capacities is prevented.

Some heavy components of the compressor or of the compressor unit may have lifting points in order to ease assembly. It shall be ensured that these component lifting points are not used as lifting points for lifting the assembled compressor or the compressor unit.

Possible measures are:

- design for removal or blinding of component lifting points after transport;
- limitation of the size of component lifting points so that only special lifting devices can be used;
- marking with special symbol (see Annex A, A.18) or giving written instructions (see 7.2.1.4 in this standard).

NOTE Bails, eyes and other lashing and lifting points exist as standardized components (see e.g. EN ISO 3266).

5.2.5.7 Lashing points

If lashing without specific lashing points will not be possible, the required lashing points shall be designed and incorporated in accordance with EN 12195-1.

The lashing points shall be designed to withstand S_1-times the load according to EN 12195-1. Although lashing points shall withstand this load, permanent deformation or defects not affecting this requirement may occur. The safety-factor S_1 shall be taken as 3 for ductile materials (see EN 13155).

Lashing points shall be designed to withstand S_2 times the load according to EN 12195-1, where S_2 = 2 without permanent deformation (see EN 13155).

It shall be ensured that these lashing points are not used as lifting points. Possible measures are:

- design for removal or blinding of lashing points after transport;

— limitation of the size of lashing points so that only special lashing devices can be used;

— marking with special symbol (see Annex A, A.19) or giving written instructions (see 7.2.1.4 in this standard).

5.2.5.8 *Portable and skid-mounted compressor units*

a) Off-road portable compressor units shall meet the following requirements:

1) for machines with a gross mass over 750 kg a parking brake system shall be fitted;

2) for machines with a gross mass less than 750 kg where a parking brake system is not fitted then 7.2.1.11 h) applies;

NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

b) When the lifting of a compressor unit is required it should preferably have only one lifting point. The design of a lifting bail or bails shall be based on:

1) a minimum vertical load of 2,5 (worst case value according to EN 13001-2) times the machine gross mass in order to account for acceleration during the lifting;

2) any additional load due to unequal distribution of machine mass.

c) Lashing points for portable and skid mounted compressor units shall be provided to allow safe securing to a vehicle on which the compressor unit may be transported. Lashing points shall be marked according to Annex A, A.21.

5.2.6 *Slip, trip and fall*

If access to elevated areas around a compressor is necessary and is an integral part of a compressor or compressor unit then these access areas shall be in accordance with EN ISO 12100:2010, 6.3.5.6.

Permanent means of access to working platforms, walkways, fixed ladders and stairways shall be in accordance with *EN ISO 14122-1, EN ISO 14122-2, EN ISO 14122-3 and EN ISO 14122-4.*

If access to elevated areas is required and is not an integral part of the compressor unit, an appropriate specification and installation instructions shall be given in the instruction handbook.

Supply and/or installation of working platforms and access to them by the user should be by formal agreement between the compressor manufacturer and the user.

5.2.7 Speed

5.2.7.1 Overspeed

Should the drive system be able to operate the compressor at speeds unacceptably higher than the maximum speed of the compressor, overspeed protection of the drive system shall be provided to avoid mechanical damage of the compressor or the compressor unit in order to protect persons and the environment.

The required performance level (PL) in accordance to EN ISO 13849-1 or safety integrity level (SIL) in accordance to EN 61508/EN 61511/EN 62061 of the safety related parts of the overspeed protection system shall be determined (for guidance, see Annex C).

5.2.7.2 Underspeed and critical speed ranges

NOTE Some components need certain rotational speeds for proper operation, for example:

If dry gas seals are operated at speeds lower than their allowable minimum speed wear is significantly increased.

If the normal operating speed range of the compressor/compressor unit is higher than the lateral or torsional natural frequency, lowering the rotational speed may result in running the compressor/compressor unit at critical speeds, which may lead to mechanical damage.

In some cases compressors may have critical speed ranges even within the overall operational speed range. These critical speed ranges are not suitable for continuous operation.

As operational times at such speeds shall be kept as low as possible, the instruction manual supplied with the compressor shall indicate procedures (e.g. start-up procedures) for avoiding excessive running within critical speed ranges (see 7.2.1.8 n)).

The required performance level (PL) in accordance to EN ISO 13849-1 or safety integrity level (SIL) in accordance to EN 61508/EN 61511/EN 62061 of the safety related parts of the underspeed protection system shall be determined (for guidance, see Annex C).

5.2.8 Loss of main energy supply or short term power interruption

NOTE Loss of main energy supply may lead to an uncontrolled situation, possibly resulting in a hazardous situation, e.g. reverse running of the compressor (see 5.2.8 in this standard), higher settle out pressure.

In case of loss of main energy supply the machine shall go into an automatic shutdown. In addition to automatic shutdown the pressure containing parts of the unit shall be either designed for settle out pressure or protected by safety relief devices relieving to a safe location, i.e. a place where the process gas cannot harm persons or environment (if applicable 5.8 shall apply).

Possible energy sources may be electric power, compressed air, steam, gas, hydraulic, etc.

Short term electric power interruptions may lead to a higher load on moving parts of the compressor unit such as couplings and gears. Possible measures to prevent damage are:

- monitoring the electric power grid and initiating an automatic emergency shutdown if the electric power interruption period is longer than acceptable;
- choice or design of the affected components such as couplings and gears for the expected load;
- consideration of torque limiting devices.

For further information, see 5.10.1 in this standard.

5.2.9 Reverse running of the compressor

NOTE Reverse running of the compressor can occur if the compressor is still connected to a pressurized system after each type of shutdown or after the loss of main energy supply (see 5.2.7 in this standard).

If reverse running of the compressor can lead to hazardous situations then suitable means to avoid reverse running shall be provided, e.g. non-return valve, brake.

5.3 Electrical safety

5.3.1 Generally applicable

The electrical equipment of a compressor unit shall be in accordance with EN 60204-1 and/or EN 60204-11 as appropriate.

In addition, compliance with EN 60079-0 and EN 60079-14 shall be achieved in applications with potentially explosive atmosphere.

5.3.2 Protection from overload

Where the compressor unit is not fitted with an over-current protection of the power circuit due to it being installed outside the compressor enclosure on site, the instruction handbook supplied with the compressor shall indicate the required precautions (see 7.2.1.5.1 in this standard).

5.3.3 Protection from live parts

Where the compressor unit is not fitted with an electrical disconnecting device, the instruction handbook supplied with the compressor shall indicate the required precautions (see 7.2.1.5.2 in this standard).

Electrical and instrument cabling shall:

- *be adequately secured and protected,*
- *not be in contact with hot surfaces;*
- *have adequate electrical insulation.*

Cabling and cabling practices shall be in accordance with EN 60204-1:2006, Clauses 6, 12 and 13.

5.3.4 Protection from lightning

Every compressor/compressor unit shall have at least one low resistant earthing point. The earthing point(s) of the unit shall be marked with an earthing symbol (Annex A, A.20).

If the compressor unit comprises safety related electronic equipment then a protection against overvoltage shall be provided according to EN 60204-1:2006, 7.9.

For further provisions, see 7.2.1.5.5.

5.3.5 *Portable and skid-mounted compressor units*

5.3.5.1 *General*

A suitable over-current protection device, e.g. fuse, shall be provided in the electrical installation to protect the wiring harness and the electric equipment. This excludes the preheat, starting and charging circuits. Where fuses are provided as over-current protection devices, a type readily available in the country of use shall be selected, or arrangements made for the supply of spare parts.

5.3.5.2 *Fluid, corrosive action*

Batteries shall be of the type with lifting handles or with lifting points. They shall be mounted and firmly secured so there is no risk of electrolyte splashing on personnel and surrounding equipment.

5.4 Control systems

5.4.1 General

Effective control system design shall be in accordance with EN ISO 12100:2010, 6.2.11 and EN 60204-1:2006, 9.4. In addition, compliance with EN 60079-0 and EN 60079-14 shall be achieved in applications with potentially explosive atmosphere. Safety systems shall be designed and evaluated using the methods of functional safety as defined in one of the following standards: EN 61508, EN 61511, EN 62061 or EN ISO 13849-1. An introduction to the methods of functional safety is given in the informative Annex C.

NOTE 1 One purpose of a control system is to maintain the values of process parameters within specified limits.

NOTE 2 The purpose of a safety related part of a control system is to monitor safety critical parameters. Exceeding the limits of those critical parameters will result in hazards. A safety system initiates suitable actions to avoid health and personnel safety hazards and limit environmental impact.

The safety system response time shall be designed in order to bring the process to a safe state. The total time between detection and the completion of action shall be less than the time for the hazardous event to occur. The maximum acceptable response time of a safety system has to be given to the user (see 7.2.1.9 c)).

NOTE 3 A typical logic solver will have a response time less than or equal to 100 ms.

The safety related controlled shutdown system and the emergency shutdown system can be initiated by different safety functions which may require different performance levels (PL) in accordance to EN ISO 13849-1 or safety integrity levels (SIL) in accordance to EN 61508/EN 61511/EN 62061.

The safety related controlled shutdown system shall comply with the highest required performance level (PL) or safety integrity level (SIL) of all the safety functions initiating the safety related controlled shutdown.

The emergency shutdown system shall comply with the highest required performance level (PL) or safety integrity level (SIL) of all the safety functions initiating the emergency shutdown.

The safety related controlled shutdown system and the emergency shutdown system may be combined in one system.

In some cases the immediate shutdown of a compressor could lead to a higher risk for persons and the environment in the overall process. A risk assessment with simultaneous consideration of the compressor and the overall process should be carried out by the operator of the compressor unit. The compressor manufacturer should obtain the conclusion. Based on this information, the compressor unit should be shutdown as soon as possible consistent with the outcome of the risk assessment. Until the compressor unit is shutdown and depressurized, additional actions e.g. use of personal protective equipment may be mandatory (see 7.2.2.2).

5.4.2 Failure of safety related control system energy supply

The system design shall be such that failure of the control system energy supply shall not result in a hazardous situation during the time of the failure or when the control system energy supply is reinstated.

In case of failure of the energy supply of the safety related control system or a part of the safety related control system the maximum safety performance of the safety related control system shall be carried out.

NOTE Possible energy sources are e.g. electrical energy, hydraulic energy, compressed air, steam, gas.

5.4.3 Start/restart

The instruction handbook for compressor units that are fitted with automatic or remote start controls shall contain provisions as given in 7.2.1.8 c) and d) of this standard.

Automatic or remote start during service, maintenance or inspection shall be prevented by an interlock included in the control system, for example a trapped key system or, if software controlled, password protection to prevent inadvertent automatic starting after each shutdown.

A protective device to prevent unintended start/restart shall be provided.

The requirements for a start and restart shall be in accordance with EN ISO 13849-1:2008, 5.2.3 and, if required, with EN ISO 12100:2010, 6.3.3.2.5.

EN ISO 13849-1:2008, 5.2.3 states that an automatic restart shall only be allowed if no hazardous situation can occur. It refers to EN ISO 12100:2010, 6.2.11.3 and 6.2.11.4 and EN 60204-1:2006, 9.2.1, 9.2.5.1, 9.2.5.2 and 9.2.6, which give the following further details:

a) EN ISO 12100:2010, 6.2.11.3 and 6.2.11.4 describe the technical rules for start, restart and stop of a machine.

b) EN 60204-1:2006, 9.2.1, 9.2.5.1, 9.2.5.2 and 9.2.6 additionally state:

   1) that measures shall be taken to prevent the movement of the machine in an unintended or unexpected manner after any stopping of the machine;

   2) that in the case where a machine has more than one control stations, measures shall be provided to prevent the initiation of commands from different control stations leading to a hazardous situation;

   3) that in the case of several control stations suitable interlocks shall be provided to secure correct sequential starting;

   4) that in the case of machines requiring the use of more than one control station to initiate a start each of these control stations shall have a separate manually actuated start control device and all start control devices shall be actuated concurrently;

   5) different type of switches that shall be used for specific functions.

5.4.4 Manual suspension of safety functions

It is not permitted to run the compressor with any automatic shutdown function suspended. As an exception to this rule, in situations where it is necessary to suspend an automatic shutdown function to maintain the safety of the process because the required proof test interval of a safety device according to EN 61508 or EN 61511 is shorter than the required operating period of the compressor, the safety function of the device to be tested shall be ensured by other appropriate measures while testing the safety device.

If it is necessary, in accordance with the previous paragraph, to temporarily manually suspend safety functions in order to test an automatic shutdown device the following requirements shall apply:

— Only one automatic shutdown function shall be under test at any time.

— The automatic shutdown function under test shall be substituted by a suitable independent device or a dedicated operator with continuous attention and with the continuous capability of an immediate manual safe shutdown should any hazardous situation arise. The substitute function shall fulfil the same requirements as the original automatic shutdown function, especially in respect of the response time and detectability.

— Every manual suspension shall be indicated, recorded and filed until the next proof test of the safety related control, but for not less than 2 years (see 7.2.1.9 h)).

In addition, the suspension of safety functions shall be in accordance with EN 60204-1:2006, 9.2.4.

Annex B provides an example of the measures necessary to ensure a safety function while testing an automatic shutdown device.

NOTE "Manual suspension of safety functions" is commonly denoted as "Trip override" or "Shutdown override".

5.4.5 Electrical control systems

5.4.5.1 Emergency stop function

All compressors shall be provided with at least one emergency stop device, unless this creates a greater hazard or the manual shall state that the user shall provide an emergency stop device (see 7.2.1.3 and 7.2.1.5.3).

The need for and provision of an emergency stop shall be in accordance with EN ISO 12100:2010, 6.3.5.2. *A manual emergency stop shall be in accordance with EN ISO 13849-1:2008, Clause 5 and specifically in 5.2.1 of that standard.*

Where an emergency stop is identified as a requirement then this shall be in accordance with EN ISO 13850. Emergency stop devices and the stop category shall be in accordance with EN ISO 13850.

If an analysis shows that the normal stop device complies with emergency stop requirements as identified in EN 60204-1:2006, 10.7.4, this is acceptable and the stop device shall be marked in accordance with EN 60204-1:2006, 10.7.3 and as shown in Annex A, A.15 of this standard.

The emergency stop device shall be coloured in accordance with EN ISO 13850:2008, 4.4.5 and as shown in Annex A, A.13 of this standard.

5.4.5.2 Manual reset

A manual reset prior to restart shall be required following a manual emergency stop or an automatic shutdown. The requirements for a manual reset shall be in accordance with EN ISO 13849-1:2008, 5.2.2 and EN 60204-1:2006, 9.2.5.3 and 9.2.5.4.

5.4.5.3 *External influences on electrical equipment*

The safety system and other electrical equipment shall be so designed and constructed that they cannot give rise to a hazardous situation in case of disturbances such as:

- *short circuiting;*
- *external impacts;*
- *interruptions or variations in the supply voltage;*
- *earthing faults.*

Hazards caused by the failure of the power supply to the safety related parts of the control system shall be prevented by employing an 'oriented failure mode system' in accordance with EN ISO 12100:2010, 6.2.12.3. This system shall have a known failure mode, e.g. bring the machine to a safe stop.

5.4.5.4 Electromagnetic phenomena

The compressor unit shall have sufficient immunity from electromagnetic disturbances particularly for signals in the monitoring and control system, which have low energy levels, to enable them to operate safely as intended and not fail to danger when exposed to the levels and types of disturbances foreseeable by the manufacturer in use. The electrical and electronic equipment of the compressor unit shall comply to the provisions of EN 61000-6-4 and EN 61000-6-2 for stationary compressor units, and EN 13309 for skid-mounted and mobile compressor units where such phenomena are identified by risk assessment to be a hazard.

The manufacturer of the compressor unit(s) shall install and wire the equipment and sub-assemblies taking into account the instructions of the suppliers of these sub-assemblies.

5.4.6 Pneumatic and/or hydraulic control systems

5.4.6.1 General

Where pneumatic and/or hydraulic equipment forms part of a safety function of a compressor unit it shall be in accordance with EN ISO 12100:2010, 6.2.10, EN ISO 4413 or EN ISO 4414 as appropriate, and the following shall apply.

5.4.6.2 *Conditioning*

Compressed air for measuring, control and safety systems shall be conditioned for the purpose and shall be in accordance with EN ISO 4414:2010, 5.4.4.2.. Hydraulic systems for measuring control and safety shall be provided with a filter system and shall be in accordance with EN ISO 4413:2010, 5.4.8.5, 5.4.5.1.3. Where the level of contamination is critical in pneumatic control systems then those levels shall be identified by an air purity classification system in accordance with ISO 8573-1. Confirmation of the level of aerosol oil contaminants shall be in accordance with ISO 8573-2, for humidity in accordance with ISO 8573-3 and for particles in accordance with ISO 8573-4.

5.4.6.3 *Pressure or fluid level drops*

A shutdown device shall be fitted to stop the compressor unit in case of the hydraulic fluid level or hydraulic or pneumatic pressure falling below the levels necessary to maintain safe operation. The shutdown device shall be in accordance with EN ISO 4414:2010, 5.4.6.2 of for pneumatic systems and EN ISO 4413:2010, 5.4.7.2 for hydraulic systems.

5.5 Thermal safety

External surfaces, subject to extremes of temperature, exposed to personnel during normal operation of the machine and which may be accidentally touched shall be avoided (e.g. by guarding, insulation, barriers) where those temperatures cannot be controlled by design.

For surface temperatures exceeding + 70 °C, see EN ISO 13732-1; for surface temperatures below - 10 °C, see EN ISO 13732-3. When guarding is not possible, there shall be an adequate warning or a symbol as identified by Annex A, A.7 (hot surface) or A.10 (cold surface).

For compressors with injection cooling appropriate measures are required to avoid the risk of hot surfaces due to overheating as a result of a lack of injection medium and ensure safe operation. This can be achieved, for example, by:

a) For safe operation of liquid injected compressors at ambient temperatures below the freezing point of the injection liquid appropriate measures shall be taken to prevent the liquid from freezing.

b) For starting of oil injected compressor units at ambient temperatures below 0°C appropriate measures shall be taken to decrease the oil viscosity before start up to ensure safe operation.

Where high or low temperature of the processed medium, lubricant or cooling medium can cause a hazard to personnel, the temperature shall be monitored and if the limits are exceeded the compressor shall be brought to a safe condition.

If the hot surfaces are an ignition source then see also 5.8 in this standard.

5.6 Noise

Design considerations shall be given to noise reduction in particular at the source, see EN ISO 11688-1, EN ISO 14163 and EN ISO 15667. Design shall be such that continuous full load operation is possible at the maximum specified ambient temperature, with all noise attenuating devices and measures in place including all the doors and access covers closed.

NOTE 1 EN ISO 11688-2 gives useful information on noise generation mechanisms in machinery.

NOTE 2 Noise may be generated by, e.g. pressure pulsations, cavitation phenomena, gas flow at high velocity, moving parts, scraping surfaces, unbalanced rotating parts, whistling pneumatics, worn parts.

5.7 Materials and substances processed, used or exhausted

5.7.1 General

The manufacturer shall obtain from the user having responsibility for the operating conditions of the compressor detailed information, including safety relevant information, about the gas and the mixture of gases to be processed.

NOTE Relevant safety information is given in EC Safety Data Sheets prepared in accordance with Directive 1907/2006/EC.

This information shall also state whether impurities/pollutants (e.g. gaseous, liquid or solid) are possible, if deposition or condensation out of the gaseous phase may occur upstream of the compressor and give the dew point of the gas at the suction and discharge sides.

In compressors handling hazardous gases, some parts of the compressor unit, e.g. filter units, may be contaminated. A potential hazard shall be avoided by providing adequate measures for, e.g. flushing the contaminated parts of the compressor with a suitable gas before opening.

When appropriate the information provided with the machine shall indicate that access to contaminated areas or parts is permitted only with personal protective equipment (see 7.2.2.2 in this standard).

Generally, for hazardous gases the following precautions shall be taken (further provisions may be necessary for some gases).

The gas dispersal into the environment shall be minimized by the following measures:

— preventing leakage of toxic, flammable or other harmful gases;

— providing appropriate shaft sealing (see 5.7.8 in this standard);

— using gaskets suitable for the gases processed at prevailing pressures and temperatures (see 5.7.9 in this standard);

— neutralizing, diluting to a safe level or venting into a safe area;

— making provisions for the safe draining and collection of polluted lubricants, drainages and deposits;

— in all accessible areas, by keeping the concentration of gases that can displace breathing air to an acceptable level.

Safe working procedures shall be specified in accordance with 7.2.2.2 in this standard.

5.7.2 Reactive gases

For gaseous or vaporous media such as, e.g. chlorine, fluorine, especially those not specifically covered in this standard, advice on hazards shall be sought from competent bodies.

If chlorine is processed the temperature of the gas in contact with carbon steel shall be less than 150 °C.

NOTE Chlorine is chemically very reactive and may react with hydrogen, hydrocarbons, ammonia or other media. At temperatures above 170 °C chlorine reacts strongly with iron and can cause complete destruction of carbon steel parts. Humid chlorine gas (>20 mg water per kg chlorine) is highly corrosive even at low temperatures. For further information, see EURO-Chlorine-Recommendation GEST 79/81 und 79/82.

Generally, the following precautions shall be taken (further provisions are made for some gases):

a) If reactions of the processed media inside the compressor are possible and will result in hazards these shall be avoided as applicable by:

   1) limiting the compression temperature by design or by installing automatically initiated emergency shutdown devices on the discharge of each casing or cylinder;

   2) preventing ignition hazard, e.g. hot surfaces or friction (see also 5.8 in this standard);

   3) choice of suitable lubricant and/or use of sparkless material pairing where friction is possible;

   4) using materials resistant to corrosion caused by the processed gas;

   5) arranging connections so that adequate purging of the compressor system with inert gas can be achieved;

   6) using filters or other appropriate measures to avoid solid impurities in the processed gas;

   7) ensuring that the compressor installation undergoes a leak tightness test at commissioning.

b) All casings, pipings, etc. shall be designed to withstand hazards by appropriate design measures like sufficient wall thicknesses.

c) appropriate means against the risk of explosion to be provided.

5.7.3 Oxygen compressors

An oxygen enriched atmosphere creates conditions for health and fire hazards in the installation area and the following safety measures for the compressors shall be taken as a minimum.

a) Ignition points shall be avoided by:

   1) ensuring adequate clearance between moving parts;

   2) selecting suitable materials;

   3) limiting the quantity and size of particles and impurities in the oxygen stream;

   4) not allowing oil and grease in the oxygen stream;

   5) avoiding corrosion, particularly by minimizing moisture;

   6) preventing any contact between oxygen and substances having combustible properties, mainly oil and greases;

7) limiting the oxygen discharge temperature by design and by installation of a high temperature initiated automatic shutdown device;

8) limiting the oxygen velocity in pipes;

9) ensuring no severe bends or sharp interior edges;

10) providing adequate cooling.

b) The choice of materials in oxygen compressors shall be optimized under consideration of the following required characteristics:

1) high ignition temperature;

2) high thermal conductivity;

3) high specific heat capacity;

4) low specific heat of combustion;

5) adequate corrosion resistance;

6) recognized quality for oxygen service of non-metallic materials, e.g. gaskets or seals;

7) coolants and lubricants that can come into contact with oxygen shall be of a quality recognized as not being flammable in oxygen service.

c) The following items are specified for piping and valves:

1) Carbon steel pipes can be used depending on oxygen pressure and velocity based on documented values accepted in the oxygen industry.

2) Valves shall be designed for low friction flow and operation.

3) Isolating and unloading valves inside the danger zone shall be remotely operated.

4) Valves shall be designed so that spindles are secure against withdrawal.

d) Maintenance and cleaning:

1) Provisions shall be made to allow thorough inspection and cleaning of the compressor, including the cooling jackets.

2) Connections, when integral with the compressor, shall be arranged so that purging of the compressor system with dry, oil-free air or inert gas can be carried out. Where such connections are not provided by the supplier, the Instruction Manual shall instruct the user that such purging is necessary.

3) Components for oxygen service shall be free of particles and rust and free from oil and grease other than lubricants recognized for oxygen service.

4) Safe working procedures shall be specified in accordance with 7.2.2.2 in this standard.

e) Hazard due to emission of oxygen:

1) All released gases, purges, drainage and leakages containing oxygen shall be discharged without hazard to personnel and provisions made for adequate dilution.

2) The venting of any oil system shall be adequately separated from any discharge with a high oxygen content.

3) Safe working procedures shall be specified in accordance with 7.2.2.2 in this standard.

NOTE For additional information, see e.g. IGC code 27/10/E.

5.7.4 Acetylene compressors

NOTE 1 Acetylene is a highly flammable and chemically unstable gas. It may spontaneously decompose resulting in deflagration with a pressure increase of about 11 times the initial pressure, or it can detonate with a pressure increase up to 350 times the initial pressure.

The following requirements are valid for compressors handling technically pure acetylene. Mixtures of acetylene with an inert gases or other gases often reduce the danger of spontaneous decomposition considerably and may increase the permitted limits for temperature and pressure. Nevertheless, the precautionary measures listed below for acetylene compressors are recommended to be followed also for mixtures of acetylene with other gases or liquids.

NOTE 2 Deviations from these requirements to accommodate mixtures with other gases require a risk assessment and the manufacturer is responsible for establishing suitable protective measures.

Acetylene compressors shall be designed and constructed such that:

a) hazards and the consequences of decomposition shall be prevented by:

   1) limiting the capacity or the power of each compression stage to a value lower than the technical possible value (derating);

   2) limiting to as small as practicable the diameter and length of gas piping;

   3) consideration of the installation of flame arrestors at the inlet and outlet of the compressor system taking into account other measures and any adverse effects which maybe introduced (e.g. increased pressure drop at the suction side by installation of a flame arrestor at the suction side may create excessive outlet temperatures).

b) The risk of decomposition shall be minimized by:

   1) considering the pressure and temperature of the acetylene to avoid liquefaction;

   2) limiting the compression temperature, by design, to a maximum of 140 °C under any foreseeable circumstances;

   3) avoiding hot spots by applying suitable lubrication, low piston speed, cooling and precautions to preclude impurities or debris of hard material;

   4) avoiding the presence of catalytic agents, which promote decomposition, e.g. iron rust, pipe scale;

   5) using materials which do not react with acetylene or other components in the processed gas. The following materials shall not be used:

      i) prohibited materials:

         I) copper and copper alloys with more than 70 % copper;

         II) for filter meshes, any copper alloy;

         III) silver and any silver alloy;

IV) mercury.

ii) prohibited materials in the presence of acetylene with lime and ammonia impurities:

I) aluminium and its alloys;

II) magnesium and its alloys;

III) zinc and its alloys, except brass;

IV) soldering when the width of the gap is greater than 0,3 mm and the solder has a content of copper more than 37 % and of silver more than 46 %. The content of copper and silver together shall not be more than 76 %.

c) To limit the hazard due to the flammability of acetylene, the following shall be taken into account

1) gas tightness of the compressor;

2) protection by avoiding effective electric, electrostatic and mechanical sparks;

3) discharge from unloading and pressure relief devices, vents, drainage and leakages;

4) connections for purging the compressor system with an inert gas;

5) remote operation of isolating and unloading valves which are inside the danger zone.

NOTE 3 For additional information, see e.g. IGC code 123/04/E.

5.7.5 Compressors for H2S containing gases

Hydrogen sulphide (H_2S) is toxic and H_2S containing gases may cause sulphide stress cracking in compressor and compressor unit materials.

Materials shall be used in accordance with EN ISO 15156-1.

In addition, the provisions of 5.8 Fire and Explosion shall be applied.

5.7.6 Nitrogen and other inert gases

Where nitrogen or other inert gases are used during compressor unit operations leakage can lead to displacement of breathing air. In all areas accessible to personnel within the compressor unit, the concentration of gases that can displace breathing air shall be such that the oxygen level is maintained within the limits identified in EN 12021.

When necessary the build-up of nitrogen or inert gases shall be controlled, e.g. by the provision of ventilation in the compressor enclosures, Installation of a venting line, to discharge the leakage to a safe area.

Safe working procedures shall be specified in accordance with 7.2.1.8 h).

NOTE Nitrogen or other inert gases are frequently used as auxiliary media for process gas compressors, e.g. as purge gases or buffer gases. During commissioning or restart after maintenance the compressor system is often flushed and temporarily operated with inert gases like nitrogen.

5.7.7 Access closures to process gas containing parts

Process gas containing parts are parts that are filled with the medium that the compressor delivers.

Access closures for the inspection and maintenance activities, e.g. in ducts, oil tanks or at the compressor can be divided into four types with the following provisions:

a) Access closures large enough to enable whole body entry and that can be opened only with tools or having a lock requiring a key, e.g. manholes fixed with bolts and nuts.

   Access closures of this type shall have provisions to avoid closing during the presence of persons inside. For example:

   1) One of the bolts shall have a crossbore equipped with a padlock with only one available key. The key can be removed and retained by the person entering the opening.

   2) A safety rope may be provided connecting the person inside with the outside.

b) Access closures large enough to enable whole body entry and that can be opened without tools or without a lock requiring a key, e.g. door with latch are not allowed.

c) Access closures large enough to enable access of body parts and that can be opened only with tools or having a lock requiring a key, e.g. sight glass, blind flange:

   access closures of this type do not require additional design features.

d) Access closures large enough to enable access of body parts and that can be opened without tools or without a lock requiring a key, e.g. hatch locked with bolt(s) and wing nut(s) are not allowed.

In addition, the provisions of 7.2.2.1 and 7.2.2.2 in this standard shall be followed.

5.7.8 Compressor shaft seal systems

Compressor shaft seals and seal systems shall be designed and constructed in such a way that a failure of one relevant element does not lead to an uncontrolled and/or unacceptable amount of leakage of hazardous process gas to the vicinity of the compressor unit (e.g. providing a double sealing with the intervening space vented or filled with a sealing medium).

Exceeding the specified acceptable process gas leakage limits shall lead to an alarm and an automatically initiated safety related controlled shutdown of the compressor. The compressor shall be depressurized (to the pressure of its environment) to a safe location, i.e. a place where the process gas can not harm persons or the environment (if applicable 5.8 shall apply).

The required performance level (PL) in accordance to EN ISO 13849-1 or safety integrity level (SIL) in accordance to EN 61508/EN 61511/EN 62061 of the safety related parts of shutdown control system and the leakage monitoring system shall be determined (for guidance see Annex C).

Additional protection can be achieved by e.g.:

— installation of gas monitoring and warning device in the vicinity of the compressor unit,

— installation of forced ventilation in the possibly contaminated area of the compressor unit,

— access to contaminated area is permitted only with personal protective equipment.

Normally the user is responsible for the provision of this additional protection. However, the situation should be clarified between the manufacturer and the user.

5.7.9 Static seals (Gaskets) for piping

Static seals shall fulfil the following requirements by being:

- suitable for the processed gas, e.g. chemically resistant and resistant to corrosion;
- heat resistant within the temperature range of the application;
- pressure resistant within the pressure range of the application;
- resistant to deformation;
- suitable for flange loading under foreseeable loads.

The following types of seals may be used as appropriate for the duty and the requirements of the previous paragraph:

- flat-ring gasket (soft, solid metal or soft with metal insertion);
- grooved steel gaskets with soft layers on both sides;
- spiral wound gasket with soft filler;
- rubber-steel gasket (off-load gasket);
- weld-ring gasket without soft insertion;
- RTJ-metal-ring joint gasket.

NOTE Design according to EN standards is usually met by applying the following standards:

- Seal geometry: EN 1514-1 (appropriate flange standard: EN 1092-1 to EN 1092-4).

Design according to ASME standards is usually met by applying following standards:

- Seal geometry: EN 12560-1 to -7 (appropriate flange standard: ASME B16.5).

Seals that are not in accordance with the above standards need to be selected for the intended use taking into account the requirements of this clause.

For gaskets with special demands (e.g. high external loading) it may be beneficial to use special flanges that avoid transmission of excessive forces to the gasket (e.g. flanges with tongue face and groove face).

5.7.10 Micro-organisms, biological and microbiological substances

5.7.10.1 *Condensate*

Drainage facilities shall be provided to minimize the accumulation of stagnant liquid, which may promote the growth of micro-organisms. The drainage systems may be either manual or automatic types and shall allow for removal of accumulated liquid from piping and accessories such as water jackets, coolers, pulsation dampers and air receivers. The provisions of 7.2.1.8 i), j) and k) of this standard shall be applied.

The compressor unit shall be equipped with, for example, drain traps to allow containment of condensate fluids and subsequent safe draining and disposal.

5.7.10.2 Water injected compressor units

The materials used in the compressor unit shall be selected to prevent the growth of bacteria in the water.

5.7.11 *Compressors units driven by internal combustion engines*

The relationship between the location of the exhaust outlet and the compressor inlet shall be such that in normal operation the exposure of the compressor inlet to exhaust fumes is minimized. In addition to this requirement the provisions of 7.2.1.8 f) and 7.2.1.11 e) of this standard shall also apply.

5.8 Fire and explosion

5.8.1 General

The manufacturer shall obtain information about any flammable or explosive materials to be used or processed and their amount. For assessment of hazard of fire and its prevention, see EN 13478.

NOTE 1 The principles applied to the prevention of fire are similar to those applied to the prevention of the risk of explosion and vice versa.

NOTE 2 For information about fire prevention for gas turbines, see ISO 21789.

If the compressor is intended to be used in a potentially explosive atmosphere the manufacturer shall obtain from the purchaser the classification of hazardous area for the intended location of the compressor unit. The manufacturer shall perform a plausibility check of this classification provided by the purchaser for the compressor unit.

When the compressor can create a potentially explosive atmosphere it shall also be checked whether the compressor or compressor unit will change the original zone classification of EN 60079-1. The compressor shall be designed to fulfil the requirements of the category which is necessary for the installation in the zone that is finally determined by taking into account the site and the influence of the compressor.

NOTE 3 The creation of a potentially explosive atmosphere by the compressor unit itself is only possible if flammable process gas is able to leak into the vicinity of the compressor.

Inside a compressor unit handling flammable gases explosion hazards only exist in the following cases:

— oxygen is part of the process gas;

— oxygen is able to enter the process gas system, e.g. the process gas pressure is permanently or temporarily lower than the ambient pressure;

— process gas is able to enter the auxiliary system (e.g. lubrication system, coupling guard).

This can occur especially after every opening of the system and has to be avoided by flushing the system with inert gases (e.g. Nitrogen). Measures have to be taken to avoid an opening of the process gas system after shutdown of the compressor if the highest temperature in the process gas system is not yet significantly lower than the ignition temperature of the flammable gas.

In case an explosive atmosphere and potential ignition source exists, an ignition risk assessment according to EN 13463-1, EN 15198 and EN 1127-1 shall be carried out.

NOTE 4 The standards EN 13463-1, EN 15198 and EN 1127-1 are harmonized to the Directive 94/9/EC.

For reactive gases like chlorine and fluorine, similar reactions as with oxygen may occur (see 5.7.2 of this standard).

To avoid the risk of fire hot piping shall not be in contact with flammable material. For insulation, material suitable for the maximum piping temperature shall be used.

Heaters for gases shall be designed and operated in such a way that their surface temperature shall not exceed the ignition temperature of the gas, e.g. by means of temperature or flow control.

In order to avoid 'hot-spots', immersion heaters used for heating lubricant shall have specific surface loading not greater than 25kW/m^2. Depending on the lubricant, the maximum permissible value can be significantly lower and shall be requested from the supplier of the heater and from the supplier of the lubricant. Then the resulting maximum specific surface loading shall not be exceeded. The heaters used shall be totally immersed in the oil at all times with low oil level monitoring. On low oil level the heaters shall be shut off in order to avoid overheating of the oil mist and possible fire in the oil reservoir. Alternatively, immersion heaters shall be equipped with a temperature limiting devices limiting the surface temperature to a maximum of 135 °C.

In case of a shutdown of the compressor due to a fire detection/alarm the oil pumps shall remain in operation until the compressor has stopped. After stopping the oil pump shall be switched off.

NOTE 5 Operating the compressor without lubrication may lead to a damage of the bearings and shaft seals with the consequence of a process gas leakage. This will probably lead to a higher hazard than stopping the oil pumps immediately.

For special provisions, see also 5.7.3 for Oxygen compressors and 5.7.4 for Acetylene compressors.

5.8.2 Electrostatic phenomena

Build-up of electrostatic charges shall be avoided by earthing all conductive stationary components.

5.8.3 *Oil-flooded rotary compressor units*

To reduce the risk of over-heating and the consequent potential for fire or explosion due to a lack of lubrication the compressor's lubrication system shall be so designed that a sufficient quantity of lubricant is injected under all operating conditions, i.e. under normal use, under abnormal conditions and operating modes not covered by safety devices, e.g. faulty starting, emergency stop.

To ensure a sufficient oil supply at least one of the following techniques shall be employed:

— *oil filters in the main circuit shall have a bypass, which is opened by the differential pressure created across the filter as the filter becomes blocked: the opening pressure to the bypass shall be determined by the volume of oil required to maintain safe operation;*

— *the provision of an alarm and/or shutdown device sensing the differential pressure across the oil filters in the main circuit: the operating pressure to the alarm and/or shutdown device shall be determined by the volume of oil required to maintain safe operation;*

— *the provision of an alarm and/or shutdown device sensing the oil pressure before entering the compressor: the alarm and/or shutdown shall be activated once the oil pressure falls below the level required to maintain safe operation.*

The design of oil-flooded rotary compressor units shall be such that the maximum temperature at the delivery flange of the compressor before the oil separator does not exceed 110 °C under normal operating conditions.

Oil-flooded rotary compressor units shall have an automatic shutdown device to switch the compressor off in the event that the temperature of the compressor oil exceeds the safe limit. The shut-down device shall be actuated at a temperature not exceeding 120 °C. Where temperatures higher than 120 °C are employed then lubricants capable of operating at elevated temperatures shall be used.

The following types of shut-down devices are acceptable;

— *temperature sensing device acting via an electronic/electrical control or;*

— *temperature indicator/gauge switch.*

The temperature measurement sensor shall be located in the discharge process gas stream such that the correct oil/ process gas mixture temperature measurement is assured.

5.8.4 Oil-lubricated reciprocating process compressor units

The following measures shall be taken into account:

- design for low compression temperatures and moderate pressure ratios for each stage;
- use of suitable lubricants;
- incorporation of a gas filter to absorb reactive impurities or impurities having a catalytic action;
- incorporation of an oil separator behind every stage and in the by-pass line to avoid any oil accumulation;
- any lubricant injected into cylinders shall be free from air or gas bubbles.

If the process gas contains oxygen (in any operation conditions) or oxygen is able to enter the process gas system (e.g. as air) then the following provisions shall be applied.

The design shall be such that the formation of oil-coke in the outlet of each compression stage is reduced to a minimum, and provision shall be made for inspecting and cleaning the process gas cooler. Provisions for inspection and cleaning may include removable covers or plugs.

The following outlet temperatures shall not be exceeded under normal operating conditions when oils rated for these temperatures are used:

- *220°C for single-stage compressors, with a maximum allowable pressure up to 10 bar;*
- *200°C for single-stage compressors, with a maximum allowable pressure greater than 10 bar;*
- *180°C for multi-stage compressors with maximum allowable working pressure up to 10 bar;*
- *160°C for multi-stage compressors with maximum allowable working pressure greater than 10 bar.*

Temperatures higher than those specified above may be permissible when oils rated for higher temperature applications are used and/or special precautions have been taken to minimize the formation of oil-coke. Minimizing the formation of coke is achieved by such measures as reducing the oil carry-over into the top of the cylinder by the use of accurately designed and fitted piston rings. In addition to these requirements the provisions of 7.2.1.6 g) of this standard shall also be applied.

5.8.5 Compressor units driven by internal combustion engines

The refuelling point on an internal combustion engine-driven air compressor unit shall be located away from any hot surfaces. The refuelling point shall be so designed as to minimize any spillage which shall be contained within the structure holding the compressor/engine by the use, for example, of a catchment tray fitted under the engine. Provision shall be made for the collected spillage to be easily drained off.

5.9 Ergonomic principles

5.9.1 General

Consideration shall be given to ergonomic design principles to include elements such as instruments which shall be located so as to be easily visible from the position at which the controls related to those instruments are operated. Controls and instruments shall be designed and arranged to assist the operator to understand their function and hence avoid operator's error. See EN 13861 and EN 614-1 for the application of ergonomic principles to machinery.

Manual controls and other frequently used devices shall be arranged to be easily reached and operated without excessive effort. See EN 61310-3 for the location of actuators on machinery.

Start and stop devices shall be easy to operate and shall be clearly marked in accordance with EN ISO 13850 and IEC 60417-DB-12M. Where separate start/stop controls are used the start control shall be identified as given in Annex A, A.11 and the stop control as given in Annex A, A.12. Where the start/stop control is combined into one device then this shall be identified as given in Annex A, A.13.

The compressor unit shall be designed and constructed to permit safe handling of fluids during filling, purging, venting, recovery and draining. See EN 614-1 for the interactions between operators and machinery during maintenance and repair.

5.9.2 Manual handling of compressor units and parts

The general provisions for easy and safe handling of compressor units and their heavy parts shall be in accordance with EN ISO 12100:2010, 6.3.5.5 and EN 1005-2 and EN 1005-3.

5.9.3 Portable and skid-mounted compressor units

If the load on the tow bar at the point where it is lifted is more than 50 kg, a mechanism shall be provided for lifting the tow bar.

Refuelling points shall be easily accessible.

NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

5.10 Integrity of machinery parts and other functional requirements

5.10.1 Generally applicable

During phases like commissioning or restart after maintenance the compressor system is often flushed and temporarily operated with gases other than the mainly used process gas (e.g. inert gases like nitrogen). The manufacturer shall obtain from the purchaser the intended operating modes (gases).

In order to prevent the breaking down of machinery parts in the intended operating modes with the specified gases at least one of the following provisions shall be taken:

— the compressor shall be designed for all foreseeable operating modes (gases), or

— adequate limiting devices shall be implemented (e.g. limiting devices for pressure and/or temperature).

5.10.2 Snow, wind and seismic loads

The manufacturer of the compressor/compressor unit shall obtain information on possible loads on the compressor/compressor unit created by snow, wind or earthquakes, if applicable, the explicit loads at the site of the compressor/compressor unit in all three dimensions. In the case of earthquake loads the manufacturer shall obtain the explicit accelerations at the site of the compressor/compressor unit in all three dimensions. If earthquake accelerations are to be considered, than at least a quasistatic calculation of the loads caused by the accelerations shall be performed by the manufacturer.

The compressor/compressor unit has to be designed in order to ensure at least a minimum operability during exposure to these loads. Minimum operability means that shutdown and depressurisation of the compressor/compressor unit is safely possible. Deformation of single components is acceptable if this does not result in a hazardous situation.

NOTE Additional guidance can be obtained from, e.g. EN 1991 (wind loads) or EN 1998-1 and EN 1998-4 (earthquake loads). National regulations may exist as well.

5.10.3 Break-up during operation

Components and assemblies shall be designed for adequate strength taking into consideration the maximum allowable working pressure, the permitted operating characteristics of pressure limiting devices (see 5.11), cyclic loads and temperature.

The shape of parts under cyclic pressure variation or other cyclic stress variations shall be chosen to reduce stress concentrations and stress levels.

Materials selected shall have sufficient ductility and fatigue resistance for the specified and foreseeable stress levels that occur. The pressure bearing parts of the compressor/compressor unit made from spheroidal graphite cast iron shall be in accordance with EN 13445-6 including verification of material properties and pressure testing. Pressure containing properties other than for spheroidal graphite cast iron shall be verified by the application of pressure testing identified at 6.1 of this standard.

Pressurized components, e.g. the head and cylinder of a reciprocating compressor or the casing of any compressor, where pressure is not a significant design requirement shall have sufficient strength, rigidity and stability to meet the static and dynamic operational effects of the compressor.

The kinetic energy of moving parts inside the compressor shall be considered in the design of the compressor. The compressor casing shall be designed in such a way that the ejection of parts from inside the compressor casing is not possible at all foreseeable events (including e.g. loss of a blade in the case of turbo-compressors or sudden blockage of a rotor pair in the case of screw compressors or roots-type compressors, ingestion of solids or fluids).

Gears and couplings shall be designed or selected in such a way that failure of these parts is not possible under normal and foreseeable operating loads (e.g. start, stop, etc.). For further information, see 5.2.8 of this standard.

Axial displacement of the compressor shaft may lead to mechanical damage of parts of the compressor e.g. shaft seal system and/or components of the compressor unit, e.g. coupling. Adequate measures shall be taken to avoid impermissible axial displacements that may result in a hazardous situation.

Materials used shall be compatible with the specified lubricants or other fluids and with the gases being processed. Lubricants or other fluids in contact with the process gas shall be compatible with the gases being processed.

Precautions shall be taken to ensure that the inter-connection of the compressor and the piping system are designed to avoid the application of unacceptable loads. The inter-connection may for instance be formed from flexible piping rated to accept the pressure of the compressed media and forces, e.g. those generated by vibration, thermal expansion.

5.10.4 Low temperature operation

Parts of the Compressor where a danger due to freezing exists shall be provided with the means of attaching devices to prevent damage from freezing during off-load or non-operational periods. These devices shall be available when compressors are used at temperatures below 0 °C, e.g. heating equipment which may be by direct heating of the coolant/lubricant functions or space heating under the enclosure of a compressor unit. The provisions of 7.2.1.6 b), c), i) and m) of this standard shall be applied.

Freezing of coolant, effects on the lubrication or on induction of liquid due to low temperature of the media being compressed or due to low temperature of the environment during starting, stopping or unloading conditions shall be prevented by suitable means.

5.10.5 Liquid shock

Liquid shock can result in almost complete destruction of the compressor unit and can therefore be the cause of the ejection of parts, the liquid causing the shock or the media processed and leakage of coolant or lubricant.

In order to prevent liquid shock either the compressor shall be of a type without internal compression or the intake of liquid in amounts likely to cause the shock shall be avoided.

Where liquid resulting from injection, priming or condensation can be present or be formed upstream or inside the compressor, adequate separators, traps and draining facilities shall be installed. If this equipment is not part of the compressor unit then the provisions of 7.2.1.8 l) of this standard shall be applied.

5.10.6 Coolant system

5.10.6.1 General

Precautions shall be taken to prevent unacceptable pressure rise in the coolant system caused by gas leakage into the coolant system. The cooling system shall be provided with a means of discharging the coolant due to the excess pressure to a safe area or a means to detect the pressure increase and then initiate a safety related controlled shutdown and activation of the depressurizing system.

NOTE The medium to be cooled can be process gas or (especially in the case of oil-flooded rotary compressors) oil in direct contact with process gas.

5.10.6.2 Application of pressure limiting devices at the cooling medium

Volumes on the cooling media side of a compressor that can be isolated and potentially subject to temperature rises, or in some cases temperature fall, shall be subject to protective measures. Those protective measures may for example include the use of expansion chambers connected to the discharge side of pressure relief devices or where acceptable direct discharge to a safe area to avoid the build-up of pressures in excess of the maximum allowable pressure for the cooling media side.

5.10.6.3 Compressor units driven by internal combustion engines

Provision shall be made to monitor and shut-down an internal combustion driven compressor unit where over-heating of the engine can cause either a breakdown of machinery parts or the risk of fire. The temperature and/or coolant level sensing device shall provide a signal to initiate for example the direct shut-off of the fuel supply to the engine or a managed shutdown through an electronic control unit.

5.10.7 Process gas temperature rise

A temperature rise of the process gas may be caused, e.g. by a failure of the coolant systems, low suction pressure or uncooled bypass operation. This could exceed the limits for safe operation of the compressor, e.g. by an unacceptable decrease of mechanical material properties of machinery parts or by an ignition risk due to high casing temperature. In these cases a temperature limiting device shall automatically initiate a safety related controlled shutdown.

5.10.8 Turbo compressor

A turbo compressor shall be protected against surging.

5.11 Pressure limiting devices

5.11.1 General

A pressure limiting device or devices shall protect pressure-containing parts if their maximum allowable pressure can be exceeded.

Permitted deviations from this requirement are:

— If the maximum allowable pressure in a compartment can only be exceeded due to external pressure supplies, the compressor manufacturer is not required to provide a separate pressure relief valve. The provisions of 7.2.1.6 k) of this standard shall apply.

— If a suitable (e.g. pressure, volume flow) pressure relief valve is provided as part of the costumers system an additional pressure limiting device is not required.

The design shall not result in the maximum allowable working pressure of any compressor compartment being exceeded. As an exception to this requirement, the maximum allowable working pressure may be exceeded by not more than 10 % as a momentary transition, e.g. if the pressure relief device is in operation. Selection of the pressure limiting device shall take into account the operational requirements for pressure and flow rate during the 10 % momentary transition phase. The pressure drop in the piping between the pressure containing part and the pressure relief device, the pressure drop of the pressure relief device itself and the pressure drop downstream of the pressure relief device when discharging at full flow shall be sufficiently low to prevent the maximum allowable working pressure of the compartment to be protected to be exceeded by more than 10 % (see EN 764-7).

NOTE Foreseeable conditions include all conditions of the intended use and the conditions of the reasonable foreseeable misuse, e.g. elevated suction pressure or decreasing suction temperature.

Devices to prevent the maximum allowable pressure from being exceeded shall be:

a) pressure relief valves; or

b) bursting discs and buckling pins; or

c) pressure sensing devices, whose performance level or safety integrity level is determined with reference to EN ISO 13849-1:2008, 4.5 or EN 61508 or EN 61511 (for guidance see Annex C). The pressure sensing devices may provide at least one of the following actions:

   1) automatically initiated emergency shutdown; or

   2) isolating the pressure system from its supply by shut-off devices; or

   3) opening of a control valve to discharge the excess pressure to a safe area.

5.11.2 Installation of pressure limiting devices

Pressure limiting devices shall be installed as close as practicable to the pressure-containing parts to be protected. Under no circumstances shall it be possible to isolate a relief device from the pressure-containing parts it is protecting.

The discharge shall be arranged so as not to create a hazard to personnel and/or the environment. Pressure relief discharge lines shall be affixed so that no excessive forces can be transmitted to the pressure relief device.

Pressure relief discharge lines shall be so designed and constructed that the collection of liquid at any point in the discharge line especially downstream of the pressure relief device is avoided.

Pressure limiting devices shall be accessible for maintenance and periodic testing.

The pressure drop in the piping between the pressure-containing parts to be protected and the pressure relief device shall not exceed 3 % of the gauge set pressure of the pressure relief device when discharging at full flow (see EN 764-7:2002, 8.4.2).

5.11.3 Design specifications of pressure relief devices

Where a pressure relief device provides a safety function to prevent allowable limits being exceeded, it shall be in accordance with EN ISO 4126-1 and EN 764-7.

5.11.4 Multi stage compressor units

All stages and intermediate sections of a multi stage compressor unit shall be equipped with pressure limiting devices set for the respective design pressures to ensure that each stage design pressure cannot be exceeded.

If it can be shown that none of the stages can be exposed to pressures higher than the final stage under all foreseeable circumstances including failure mode conditions, and each stage and intermediate section is designed for the maximum allowable working pressure of the final stage, then only the final stage requires a pressure relief valve.

5.11.5 Single and multi stage turbo compressors

All stages and intermediate sections of a multi stage compressor unit shall be designed for the maximum pressure at this specific stage and intermediate section that could arise under all foreseeable circumstances including failure mode conditions taking into account the settle out pressure.

If the design cannot fulfil this requirement, additional pressure limiting devices at each stage or intermediate section shall be provided.

A pressure limiting device on the discharge side of a single or multi stage turbo compressor is not necessary if both of the following requirements are fulfilled:

— the compressor operating at the maximum occurring suction pressure by design cannot attain a discharge pressure of more than 110 % of the maximum allowable working pressure, and

— the suction pressure of a turbo compressor can, by design, not exceed the specified value (comparable to atmospheric suction) or a pressure limiting device is in use in order to avoid an increase of the suction pressure.

5.12 Information and warning devices

A suitable pressure indicator shall be provided either on the compressor unit or at a relevant remote control position to display the pressure:

— *existing at the final outlet of a compressor,*

— *in each separate stage of diaphragm compressors with a maximum allowable pressure exceeding 3 bar;*

— *on the pressure side of each separate stage of positive displacement compressors having a shaft input power of more than 20 kW;*

— *of lubricant systems equipped with oil pumps on compressors having an input power of more than 75 kW;*

— *at the inlet of a compressor having inlet pressure above atmospheric.*

For additional information on pressure gauges see EN 837-2. Where pressure transducers are used in conjunction with an electronic display the accuracy of the reading shall be equal to or better than the equivalent pressure gauge identified in EN 837-2.

If mechanical pressure gauges are used they shall be of class S2 or S3 according to EN 837-2 if one of the following applies:

- mechanical pressure gauges with a casing diameter exceeding 63 mm and a maximum allowable working pressure exceeding 10 bar are used;
- the pressure of hazardous gases is to be measured.

NOTE Class S2 and S3 of EN 837-2 describe safety pressure gauges which can withstand higher pressures (see also EN 837-1 and EN 837-3).

6 Verification of safety requirements and/or protective measures

6.1 Pressure testing

6.1.1 *General*

The components or assemblies forming the pressurized gas side and coolant side of the compression space other than the compressor casing itself shall be tested in accordance with applicable standards, e.g. EN 13445-5:2009, 10.2.3.

For parts with a maximum allowable working pressure greater than 2000 bar a test pressure equivalent to 1.3 times the maximum allowable pressure shall be applied. The test procedure shall be in accordance with EN 13445-5:2009, 10.2.3.

For compressor produced in batches and designed to operate at a maximum allowable working pressure not greater than 16 bar, sample testing is allowed if the energy content of the component does not exceed 200 bar litres.

NOTE Compressor casings are designed with regard to stiffness. This normally imposes the highest requirements and therefore the pressure vessel code is not applicable. Nevertheless, a pressure test is performed in order to prove the mechanical integrity of the part.

6.1.2 Acetylene compressors

The ability of acetylene compressors to withstand elevated pressure in case of deflagration shall be tested in accordance with Table 2.

Table 2 — Test pressures

Max. allowable working pressure, PS, bar	Test pressure, bar
PS < 0,2	3,75
0,2 ≤ PS < 0,4	12
0,4 ≤ PS < 1,5	25
PS ≥ 1.5	11 x PS+10

6.2 Leak tightness test for hazardous gases

Leak tightness of the gas containing parts of the fully assembled compressor units and associated pipelines shall be tested with a pressure between 1,0 and 1,1 times the maximum allowable working pressure of each process stage/section.

Testing for leakage shall be carried out with inert gas, air, processed gas or whatever is suitable and safe. If processed gas is used the test may be made under operating conditions. The tests may be made during commissioning.

The leak tightness test shall be made with a gas which has a lower or comparable mol weight not greater than that of the processed gas.

6.3 Test of electrical loops

The test of electrical equipment and devices shall be in accordance with EN 60204-1:2006, Clause 18.

6.4 Test of control systems

All safety related control devices, instruments and safety related parts of control systems shall be tested at least before the commissioning of the compressor unit.

Periodic (proof tests) during use should be in accordance with the information given in the instruction handbook (see 7.2.1.9 g)).

If muting or suspension of safety related control functions or machine protection functions is required for testing the safety of the compressor unit shall be ensured during the test if necessary by other means (for further information, see Annex B). Precautions to be taken during muting or suspension shall be given in the instruction handbook, see 7.2.1.9 h) in this standard.

6.5 Noise

6.5.1 *General*

The noise emission values, i.e. the A-weighted emission sound pressure level at the workstation and the A-weighted sound power level, shall be measured, reported, declared and verified in accordance with EN ISO 2151.

Compliance with 5.6 in this standard may be verified through the use of the noise emission values with those for other machines of the same family, of similar size and performance characteristics.

6.5.2 *Sound power level of compressors used outdoors*

The sound power level of compressor units for use outdoors is subject to a specific European Regulation. As an exception to 6.5.1, the determination of the sound power level for such compressor units shall comply with this regulation.

NOTE The current specific European Directive (2000/14/EC) specifies limit values of the sound power level only for compressors <350 kW. For compressors above that power limit (**>=** 350kW) Directive 2000/14/EC is not applicable and consequently only 6.5.1 applies.

6.6 Stability of portable compressor units

The safe road towing stability of a portable compressor shall be verified by practical tests. The test shall be conducted on a portable compressor loaded as intended for use, e.g. including fuel, hoses and tools. Tyre pressures shall be adjusted as specified in the instructions for use. The portable compressor unit shall be towed on a representative highway road surface for use at intended road speeds up to the maximum rated speed as given in the information for use.

6.7 Structure of verification

One or more of the following methods may be required for appropriate verification:

— visual check (inspection);

— functional check;

— measurement / test;

— calculation / simulation.

Table 3 gives suggestions for commonly used verification methods for each safety requirement or measure.

Table 3 — Structure of verification

Safety requirements or measures	Visual check (inspection)	Functional check	Measurement/ Test	Calculation/ Simulation	Reference to other standards
5.2 Mechanical safety					
5.2.2 Guards	X		X		
5.2.2.1 Fixed guards	X				EN 953
5.2.2.2 Cutting and severing	X				EN 953
5.2.2.3 Bodily contact	X		X		EN 953
5.2.2.4 Ejection of parts				X	EN 953
5.2.2.5 Openings in guards	X	X			EN ISO 13857
5.2.2.6 Access closures	X	X			EN 953 EN 547-1
5.2.3 Fluid injection	X				
5.2.4 Loss of stability	X			X	
5.2.5 Lifting and transport	X			X	
5.2.6 Slip, trip and fall	X		X		EN ISO 14122-1 EN ISO 14122-2 EN ISO 14122-3 EN ISO 14122-4
5.2.7 Speed					
5.2.7.1 Overspeed		X	X		EN ISO 13849-1 EN 61508 EN 62061 EN 61511
5.2.7.2 Underspeed and critical speed ranges			X		EN ISO 13849-1 EN 61508 EN 62061 EN 61511
5.2.8 loss of main energy supply				X	
5.3 Electrical safety					
5.3.2 Protection from overload	X				EN 60204-1 EN 60204-11
5.3.3 Protection from live parts	X		X		EN 60204-1 EN 60204-11
5.3.4 Protection from lightning	X				

Table 3 (*2 of 5*)

Safety requirements or measures	**Visual check (inspection)**	**Functional check**	**Measurement/ Test**	**Calculation/ Simulation**	**Reference to other standards**
5.3.5.2 Fluid, corrosive action	X				
5.4 Control systems					
5.4.1 General 5.4.2 Failure of safety related control system energy supply 5.4.3 Start/restart 5.4.4 Manual suspension of safety functions [a]	X	X	X	X	EN ISO 12100 EN 60204-1 EN 60079 EN ISO 13849-1 EN 61508 EN 61511 EN 60204-1
5.4.5 Electrical control systems					
5.4.5.1 Emergency stop	X	X			EN ISO 12100 EN ISO 13849-1 EN ISO 13850 EN 60204-1
5.4.5.2 Manual reset	X	X			EN ISO 13849-1 EN 60204-1
5.4.5.3 External influences on electrical equipment	X	X			EN ISO 12100
5.4.5.4 Electromagnetic phenomena					EN 61000-6-4 EN 61000-6-2 EN 13309
5.4.6 Pneumatic and/or hydraulic control systems					
5.4.6.2 Conditioning	X				ISO 8573-2 ISO 8573-3 ISO 8573-4
5.4.6.3 Pressure or fluid level drops		X			
5.5 Thermal safety	X	X	X		EN ISO 13732-1 EN ISO 13732-3

Table 3 (*3 of 5*)

Safety requirements or measures	**Visual check (inspection)**	**Functional check**	**Measurement/ Test**	**Calculation/ Simulation**	**Reference to other standards**
5.6 Noise	X		X		EN ISO 2151 EN ISO 11688-1 EN ISO 14163 EN ISO 15667
5.7 Materials and substances processed, used or exhausted					
5.7.2 Reactive gases [a]	X	X	X	X	GEST 79/81 and 79/82
5.7.3 Oxygen compressors [a]	X	X	X	X	IGC code 27/10/E.
5.7.4 Acetylene compressors [a]	X	X	X	X	IGC code 123/04/E
5.7.5 Compressors for H2S containing gases [a]	X	X	X	X	EN ISO 15156-1
5.7.6 Nitrogen and other inert gases	X		X		EN 12021
5.7.7 Access closures to process gas containing parts	X				
5.7.8 Compressor shaft seal systems	X		X		EN ISO 13849-1 EN 61508 EN 61511 EN 62061
5.7.9 static seals (gaskets) for piping	X		X		EN 1514-1 EN 12560
5.7.10 Micro-organisms, biological and microbiological substances	X				
5.7.11 compressor units driven by internal combustion engines	X				
5.8 Fire and explosion					
5.8.1 General	X				EN 13478 EN 60079-1 EN 13463-1 EN 15198 EN 1127-1
5.8.2 Electrostatic phenomena	X		X		
5.8.3 Oil flooded rotary compressor units		X	X		

Table 3 (*4 of 5*)

Safety requirements or measures	Visual check (inspection)	Functional check	Measurement/ Test	Calculation/ Simulation	Reference to other standards
5.8.4 Oil-lubricated reciprocating process compressor units		X	X		
5.8.5 Compressor units driven by internal combustion engines	X				
5.9 Ergonomic principles					
5.9.1 General	X				EN 614-1 EN 13861 EN 61310-3 EN ISO 13850 IEC 60417-DB-12M
5.9.2 Manual handling of compressor units	X				EN ISO 12100 EN 1005-3
5.9.3 Portable and skid-mounted compressor units	X		X		
5.10 Breaking down of machinery parts and other functional disorders					
5.10.1 Generally applicable		X			
5.10.2 Load of snow, wind and earthquakes	X			X	
5.10.3 Break-up during operation	X		X	X	EN 13445-6
5.10.4 Low temperature operation	X	X			
5.10.5 Liquid shock	X				
5.10.6 Coolant system					
5.10.6.1 General	X	X			
5.10.6.2 Application of pressure limiting devices at the cooling medium	X	X			
5.10.6.3 Compressor units driven by internal combustion engines	X	X			
5.10.7 Process gas temperature rise	X	X			
5.10.8 Turbo compressor (surge protection)		X	X		

Table 3 (*5 of 5*)

Safety requirements or measures	**Visual check (inspection)**	**Functional check**	**Measurement/ Test**	**Calculation/ Simulation**	**Reference to other standards**
5.11 Pressure limiting devices					
5.11.1 General	X	X			EN ISO 13849-1 EN 61508 EN 61511 EN ISO 12100
5.11.2 Installation of pressure limiting devices	X		X	X	EN 764-7
5.11.3 Design specifications of pressure limiting devices	X	X			EN ISO 4126-1
5.11.4 Multi stage compressor units	X	X		X	
5.11.5 Single and Multi stage turbo compressors	X	X		X	
5.12 Information and warning devices	X				
[a] The verification depends on the respective safety related control system.					

7 Information for use

7.1 *General requirements*

The requirements for 'information for use' shall be in accordance with EN ISO 12100:2010, 6.4 and this clause. Documentation drawn up by the manufacturer shall be supplied with each compressor/compressor unit to cover its intended use. It shall lay down procedures for safe installation, use, maintenance and disposal and shall warn against known dangerous practices, misuses and residual risks.

The text shall be simple, adequate, complete and be suitable for the personnel responsible for the compressor/compressor unit. Where a compressor unit may be used by non-professional user then information for use should be written in a form that is readily understood by the non-professional user.

The documentation supplied shall be appropriate to the complexity of the compressor/compressor unit and shall consist of:

a) *Instruction handbook, including safety relevant instructions for both the owner and operator.*

   The instruction handbook shall be kept permanently with the compressor and be available for the operator.

b) *Service instruction, comprizing the instructions for the tasks to be carried out by specialized personnel.*

c) *Specification of spare parts to be used, where these affect the safe use of the compressor unit.*

The information identified may appear in more than one document.

7.2 Accompanying documents

7.2.1 *Instruction handbook (Operating Manual)*

7.2.1.1 *General*

The requirements of the instruction handbook shall be in accordance with EN ISO 12100-2:2003, 6.5 and the following where applicable. An indication that the instruction handbook shall be read shall be placed on the compressor unit. The marking shall be as identified in Annex A, A.1.

It may be necessary to make changes on the instruction handbook during commissioning. It is sufficient if these are made by replacement of the relevant parts of the document or additions to it.

7.2.1.2 Data plate information

The same information as on the data plate (see 7.3.4 of this standard).

7.2.1.3 General description of the compressor/compressor unit (in principle)

- Compressor (including physical working principle and type);
- drive system (if applicable);
- any main component or device supplied which is necessary for operation;
- flow path of the medium processed;
- starting and stopping;
- emergency stop controls, their location, function and use if provided by the manufacturer.

7.2.1.4 Information relating to transportation and storage of the compressor/compressor unit

This information shall include (see EN ISO 12100):

- gross mass;
- outer dimensions;
- location of center of gravity;
- location of lifting points and lashing points, if applicable;
- drawings indicating application points for lifting equipment and lashing;
- indication that it is prohibited to use lashing points for lifting;
- indication that the use of lifting devices which can develop accelerations higher than 2,5 times the acceleration of gravity is prohibited;
- indication of the maximum allowable hoisting class and lifting velocity according to EN 13001-2 if the maximum dynamic load factor (see 5.2.5.2.2) was calculated considering a maximum acceleration lower than 2,5 times the acceleration of gravity;
- storage conditions;

— preservation measures (e.g. filling with nitrogen, application of conservation wax).

7.2.1.5 Information relating to installation and commissioning of the compressor/compressor unit

7.2.1.5.1 Over-current protection

Where over-current protection of the power circuit is not supplied then a statement shall be made that the user should make provision for the installation of the over-current protection of the power circuit. Information relevant to this provision shall be given, e.g. current, voltage, phases. The instructions shall make reference to the over-current protection being in accordance with EN 60204-1:2006, 7.2.

7.2.1.5.2 Electrical disconnecting device

Where an electrical disconnecting device is not supplied then a statement shall be made that the user should make provision for the installation of the electrical disconnecting device of the power circuit. Information relevant to this provision shall be given, e.g. current, voltage, phases. The instructions shall make reference to the supply disconnection device being in accordance with EN 60204-1:2006, 5.3.

7.2.1.5.3 Emergency stop device

Where an emergency stop device is not supplied then a statement shall be made that the user should make provision for the installation of at least one emergency stop device.

7.2.1.5.4 Additional information relating to installation

Information shall be provided for the correct installation of the compressor/compressor unit. Due to the variation in the design of process gas compressors / compressor units and their application the information required may vary. Information may be necessary regarding for example, the prime mover, prime mover alignment, foundation requirements and grouting of machine components, assembly of piping components, permissible flange connection moments and forces applied to flange connections, structure of the oil system, cleaning of pipes , as appropriate.

In addition the rated power of all installed electric motors and if applicable other electrical consumers shall be given. Any additional information given shall be in accordance with EN 60204-1:2006, 16.4.

7.2.1.5.5 Additional information relating to commissioning

Due to the variety of process gas compressors / units and the variety of their applications information may be necessary regarding checks/functional tests of (if applicable) e.g. tightness, earthing, electrical circuits, seals, control systems, safety related controls, electrical connections, process gas and auxiliary connections, etc.

Information shall include:

— the position of one or more earthing point(s),

— the requirement that at least one earthing point shall be connected to the earthing system on site, and

— an indication that additional earthing and lightning protection shall be erected by the operator on site if necessary,

— an indication that earthing and electrical shielding to protect cables shall be checked before putting into service.

7.2.1.6 Information related to the intended use of the compressor/compressor unit

a) Intended media (including media processed and media temporarily used, e.g. for flushing) and information on the permitted grade of contamination;

b) inlet, intermediate and discharge temperatures;

c) inlet, intermediate and discharge pressures;

d) maximum pressure ratio or maximum pressure difference (depending on which parameter is the limiting one);

e) auxiliary media (seal, purge and buffer gas) including thermodynamic conditions, quality, and quantity;

f) specification of lubricants and filters concerning quality, quantity and recommended frequency of replacement;

g) specification of hydraulic transmission fluids;

h) limiting pressures and temperatures of the lubrication system;

i) maximum and, if applicable, minimum and/or prohibited speeds;

j) protective devices (e.g. pressure limiting devices). Where these are not supplied with the compressor, a statement shall be made that the user should make provision for the installation of the indicated pressure limiting devices and other protective devices. Information relevant to this provision shall be given, e.g. pressure, flow rate;

k) if the compressor is not intended for use in a potentially explosive atmosphere a warning shall be given;

l) the following information on the operation of compressors at an ambient temperature below 0 °C:

  1) precautions to prevent ice and snow interfering with the operation of the machine, in particular that pressure limiting devices, air filters of the compressor unit and of the cooling air may be blocked;

  2) actions to be taken to prevent the freezing of cooling water systems, water traps, valves and fittings;

  3) measures to avoid the freezing of accumulations of condensate;

  4) actions to be taken to prevent malfunction of the control system;

  5) the specification of lubricants for low temperatures or measures to be taken to raise the temperature of the lubricating system;

m) warnings shall be given that high oil viscosity during cold start up, clogged oil filters or valve malfunction can result in oil starvation resulting in mechanical damage;

n) to prevent the risk of oil fires occurring information shall be given on:

  1) the choice of oil;

  2) the operation and maintenance of the compressor.

  3) that information on reducing the risk of oil fires shall give details for:

    i) regular and complete oil changes;

ii) ensuring that the oil cooling arrangements are kept clean and protective devices maintained in working order;

iii) the regular checking and maintenance of the oil level;

o) information about used flammable or explosive materials including the amount that could be present (see 5.8.1 in this standard);

p) where guards are provided that, in accordance with Clause 5 are not interlocked, e.g. flywheel guards when required for barring over the compressor and to provide access to timing marks, wheel hub covers, oil level gauge instructions shall be given to inform the operator that access closures shall be closed when the compressor is in operation. A sign stating "Access for maintenance only keep closed" shall be provided in a prominent position and close to the movable guard where the guard is not self closing;

q) steps necessary to avoid the transmission of unacceptable loads to piping systems where they inter-connect with the compressor/compressor unit shall be specified, e.g. the use of flexible hoses;

r) the limit of safe ambient operating conditions.

If sensing devices for certain process parameters exist, their associated alarm values and automatically initiated shutdown values shall be stated.

A warning that the operating conditions (e.g. pressure ratio, used process gas) shall not be changed without a reassessment of the design carried out by the user in cooperation with the manufacturer of the compressor.

7.2.1.7 Information on regular maintenance

The information on regular maintenance shall include, e.g.*:*

a) instructions for simple routine servicing and simple repairs together with general drawings and diagrams, when required, and appropriate safety procedures;

b) the requirement for pressure relief valve maintenance and testing at regular recommended intervals to confirm their correct operation at their specified setting;

c) frequency of the cleaning of coolers (e.g. in the case of dust-loaded environments coolers shall be frequently cleaned to avoid overheating of the compressor).

7.2.1.8 Information related to the residual risks of the use of the compressor/compressor unit

Taking into account the variety of process gas compressors / compressor units and their application the following information on residual risks shall be provided as appropriate:

a) the user shall be provided with any necessary warnings for explosive, toxic or otherwise harmful gases;

b) operation with lids and doors shut if the compressor unit is designed to be operated in this mode;

c) identifying the actions necessary to prevent starting automatically or from a remote position when the compressor is being serviced, maintained or inspected, e.g. locking in the “off” position of the main electrical breaker switch, in the case of steam driven systems providing a means of isolating the steam inlet valve to a steam turbine and locking this in the “off” position;

d) indication of automatic or remote control of the compressor / compressor unit using the sign as given in Annex A, A.5;

e) location of excessively hot or cold surfaces;

f) an indication of when there is a risk of inhalation of hazardous or harmful gases, mists or fumes and that personal protective equipment shall be worn when accessing contaminated areas or parts;

g) risk of coke formation in the delivery piping causing a fire or explosion (reciprocating compressor);

h) information shall be given that in all areas accessible to personnel, the concentration of processed gases that can displace breathing air shall be kept within acceptable levels. Reference shall be made to see EN 12021 for acceptable levels of contaminants in breathing air;

i) quality of the injection fluid supplied for fluid-injected compressors;

j) in the case of water cooled compressor units the user should be advised as to the risks associated with the use of open circuit cooling towers, e.g. growth of Legionella pneumophila bacteria;

k) information to allow the safe containment and disposal of contaminated condensates;

l) the need for separators, traps and draining facilities required to process liquids produced by the compressor before putting the compressor unit into use if these are not supplied;

m) a recommendation for the use of hearing protectors, if appropriate;

n) underspeed and critical speed ranges where operational times shall be kept as low as possible. In addition the maximum start-up time or a suitable start-up curve may be given to assist meeting this objective;

o) information that following a shutdown of the compressor/compressor unit due to a fire alarm the oil pumps shall remain in operation until the compressor has stopped. After stopping the oil pump should be switched off.

7.2.1.9 Information relating to the safety related controls of the compressor/compressor unit

For those safety related control systems that are part of the compressor or the compressor unit are within the scope of supply of the manufacturer and are considered to have a minimum SIL-1 or PL-a (see Annex C), the following information shall be included in the documentation:

a) description of the risk, which is reduced or limited by the respective safety related control and including the information about the required safety performance (PL-Level or SIL-Level) of the respective safety related control. Indication that a suspension (overriding) of a safety function is generally prohibited;

b) a clear, comprehensive description, e.g. by overview (block diagram) of the safety related parts of the control system, e.g. interfaces and architecture;

c) response time of the control system;

d) power supply requirements and specification of the connection to the power supply(ies) of the site and if applicable to the superior safety related control system;

e) if the safety related control system cannot be completed by the manufacturer of the compressor or compressor unit, information on safety-related parameters of the safety related control or parts of the control shall be provided by the manufacturer of the compressor/compressor unit for the final evaluation of the system by the user (see Annex C);

f) information on operating limits of the safety related control system and the physical environment (for example lighting, vibration, noise levels, atmospheric contaminants, temperature and humidity) where appropriate;

g) information (as applicable) on:

1) indications and alarms;

2) sequence of operation(s);

3) frequency of inspection;

4) frequency and method of periodic testing (proof test);

5) guidance on the adjustment, maintenance, and repair of the safety system;

6) recommended spare parts list; and list of tools supplied, if applicable.

h) a description of the safeguarding and of the means provided to give protection should the muting or suspension of protective devices be necessary, e.g. setting or maintenance, (see Annex B); every manual suspension shall be indicated, recorded and filed until the next proof test of the safety related control;

i) information on the residual risks due to the adopted safety related control, indication of whether any particular training is required and specification of any necessary personal protective equipment;

j) if applicable, a list of means for easy and safe trouble shooting;

k) alarm values and automatically initiated shutdown values shall be stated.

The documentation requirement can be fulfilled by integration of all documentation of all parts of safety related controls into the documentation for the compressor or compressor unit.

For those safety related controls that are not part of the compressor or the compressor unit and/or not in the scope of supply of the manufacturer necessary information for the safe operation of the compressor unit shall be stated. For example, the following information may be appropriate:

— the maximum response time required for safe operation;

— the required SIL or PL, when applicable;

— the required actions to implement the required safety related control.

7.2.1.10 Noise

The instructions shall include:

— *the value of the A-weighted emission sound pressure level at the workstation. The value of the associated uncertainty shall be given in accordance with EN ISO 2151:2008, Clause 8;*

— *the value of the A-weighted sound power level where the A-weighted emission sound pressure level at the workstation exceeds 80 dB(A). The value of the associated uncertainty shall be given in accordance with EN ISO 2151:2008, Clause 8;*

— *the reference number of the noise test code, EN ISO 2151:2008;*

— *exceptionally for compressor units for use outdoors the value of the declared A-weighted sound power level shall be a single number, i.e. the sum of the measured value and the value of the associated uncertainty, according to the relevant regulation.*

7.2.1.11 Portable and skid-mounted compressor units

In addition, the information for use shall contain the following information for specific types of compressors:

a) *all necessary instructions for correct operation, inspection, lifting and transportation;*

b) *a warning that all hoses and fittings shall be suitable for site use at the maximum allowable pressure of the portable compressors;*

c) *a recommendation that for pressures above 7 bar, delivery hoses should be fitted with a safety cord, e.g. wire rope;*

d) *information on the greatest permissible inclination from the horizontal;*

e) *warning against the use of an internal combustion engine-driven compressor in a confined space. In addition a warning according to Annex A, A.9 shall be applied to the compressor unit;*

f) *before towing a portable compressor:*

   1) *the jockey wheel or support stand is raised;*

   2) *the coupling is securely fastened to the towing vehicle;*

   3) *a safety device is installed to stop the compressor if the towing connection fails while towing;*

   4) *lighting leads are correctly connected;*

   5) *parking brake to be disengaged, where fitted;*

g) *the appropriate purging of associated piping and equipment;*

h) *where a parking brake is not fitted the use of wheel chocks shall be recommended when parked and in use.*

NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

7.2.2 Service instructions

7.2.2.1 General

The service instructions shall identify the work that is in addition to the routine checks, cleaning and replacements identified in 7.2.1.7 of this standard.

The manufacturer shall identify in the service instructions the service work which can be performed by non-specialized personnel, specialized personnel and specialized personnel authorized by the manufacturer. The manufacturer shall provide at least the necessary information for work that can be performed by non-specialized personnel and specialized personnel not requiring the authority of the manufacturer sufficient to carry out the work correctly.

NOTE Specialized personnel authorized by the manufacturer is expected to have access to the relevant information by means other than the service instructions.

The service instructions shall include:

- a list of spare parts for safety critical use;
- general drawings and diagrams;
- list of parts and consumables that need periodic inspection or replacement;
- instructions for fault analysis;

- schedule for periodic inspection and replacement of parts and consumables;
- instructions for inspection and cleaning of the compressor/ compressor unit;
- instructions for routine servicing and simple repairs together with the appropriate safety procedures;
- instructions on how to enable service work and subsequent testing to be carried out safely on compressor units in multiple (parallel or serial) installations;
- instructions on how to safely start, stop and isolate any unit, independently of the other compressor units, in a multiple installation (parallel or serial);
- if applicable, instructions on the use of a restraint attached to the outside of an opening and to the maintenance personnel of a length sufficient only to allow access to the item being inspected or serviced, e.g. silencer. An instruction that the restraint used and the attachment should be inspected before each use for effectiveness (see also 5.7.7);
- address(es) of maintenance agent(s) approved by the manufacturer, if any.

The manufacturer shall provide a list giving information on all relevant parts used for servicing with an unambiguous identification, and indicating the location of the part on the compressor.

7.2.2.2 Precautions for service/maintenance

The following minimum information is to be provided so that service and maintenance actions may be carried out safely:

- *disconnection from <u>all</u> energy supplies, including auxiliary supplies;*
- *measures against reconnection, including the need to display a sign using Annex A, A.3 and A.8;*
- *display a sign using Annex A, A.3 and A.8;*
- *neutralizing of residual energy, e.g. discharge of electrical devices, depressurizing, unloading springs;*
- *testing of the safe state of the machine (absence of energy).*

In addition:

- If flammable or explosive gas or oxygen is handled, it shall be stated that before and after every opening of the system it has to be flushed with inert gases (e.g. Nitrogen).
- If toxic gas is handled, it shall be stated that before every opening of the system it has to be flushed with inert gases (e.g. Nitrogen).
- Before opening any access closure to a process gas containing part this part has to be isolated from the system, vented and (if required) purged. If isolation is not possible the compressor has to be stopped, be protected against unintentional start/restart according to 5.4.3 in this standard and the whole compressor unit has to be isolated from the system, vented and (if required) purged. The provisions of 5.7.7 of this standard shall be followed. Purging is required if other means to protect persons and environment (e.g. use of personal protective equipment) are not in place.
- Components for oxygen compressors/units shall be free of particles and rust and free from oil and grease other than lubricants recognized for oxygen service.
- If flammable or explosive gas is handled which measures shall be taken to avoid an opening of the process gas system after shutdown of the compressor if the highest temperature in the process gas

system is not yet significantly lower than the ignition temperature of the flammable gas (see 5.7.2 and 5.8.1).

- Precautions to be taken if the compressor unit is required to be operational during service/maintenance.
- Where service, maintenance or inspection activities require access to the inside of an enclosure, instructions shall be given to indicate safe entry procedures taking into account measures provided in accordance with 5.2.2.5 of this standard.
- Warnings shall be given of the hazards of opening and entering intake ducts and compressor/compressor unit enclosures.
- When locks with keys are used to control access to hazardous areas the distribution of keys shall be restricted to authorized personnel (see 5.2.2.5).
- Only one key of the padlock or similar device used to retain a door in open position shall be available. The information for use shall describe procedures to be adopted by persons entering the enclosed space including the need for the person entering the enclosed space to retain the key.

  In addition, a warning shall be given on the access door to identify the need for retaining the door in the open position and preventing the machine from starting.

Other specific information such as the requirement to remove lubricants, cooling water supplies or condensate shall also be given as required and in accordance with the complexity of the compressor unit. When reviewing the information to be provided, this shall be in accordance with EN 626-1:1994+A1:2008, 7.1.4, 7.1.5 and 7.2.

Where access is required for ease of service or maintenance and this will be achieved by the use of ladders or platforms this information shall be provided.

7.2.3 Dismantling

Information on safe dismantling, disabling and disposal shall be provided. This will include safe disposal of all fluids used in the compressor unit such as lubricants, coolants and refrigerant gases, and shall be in accordance with EN 626-1:1994+A1:2008, 7.1.4. Compressor units containing materials which may be classified as hazardous substances when scrapped and where specific disposal methods are required, this information shall be given.

Information that if a process compressor has to be dismantled for, e.g. maintenance, storage or transportation, it should be decontaminated as necessary and a declaration of decontamination provided shall be given.

7.2.4 Qualification

Requirements for the qualification of operators of specialized personnel shall be stated.

7.3 Markings, signs and written warnings

7.3.1 Generally applicable

Signs and warnings fixed to the machine shall be durable and their requirements shall be in accordance with EN 61310-2:2008, Clause 7.

Where the relevant hazard exist appropriate symbols from Annex A shall be applied to the machine and a list of the symbols used with an explanation of their meaning shall be included in the instructions for use.

The direction of rotation shall be marked on the compressor by means of an arrow, as given in Annex A, A.14.

If relevant, a sign to recommend the use of hearing protectors, as given in Annex A, A.2 shall be displayed.

7.3.2 Compressor unit enclosures

A warning sign in accordance with Annex A, A.6 for touchable hot surfaces and Annex, A.9 for touchable cold surfaces shall be provided. These warnings shall be affixed at access points to the enclosure (see also 5.5).

7.3.3 Portable and skid-mounted compressor units

The following warning signs shall be attached to the compressor unit:

a) to operate only with doors and lids closed, as given in Annex A, A.4;

b) that the outlet cocks of the compressor shall not be opened unless a hose is attached, as given in Annex A, A.5;

c) for hot surfaces, as given in Annex A, A.6;

d) stating the correct fuel at the point of refuelling;

e) marking of input point for fuel, as given in Annex A, A.15;

f) marking of input point for oil, as given in Annex A, A.16;

g) marking of input point for coolant, as given in Annex A, A.17;

h) marking of the specified tyre pressure;

i) marking of lashing and lifting points, as given in Annex A, A.18 and A.19.

NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

7.3.4 Markings (in particular, data plate)

7.3.4.1 Generally applicable

Markings, including data plates, shall be permanently attached and clearly visible.

Compressor units shall have a data plate(s) with at least the following information:

a) business name and full address of the manufacturer and, where applicable, his authorized representative;

b) mandatory marking, when appropriate [2)];

c) year of manufacture (that is the year in which the manufacturing process is completed);

d) designation of series or type, if any;

e) serial or identification number, if any;

f) rating information to include the following (for each section as applicable);

   1) maximum allowable pressure at the outlet of the compressor, expressed in bar;

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2) For machines and their related products intended to be put on the market in the EEA, CE marking as defined in the applicable European Directive(s), e.g. Machinery, Noise from equipment used outdoors, and Pressure Equipment.

2) maximum continuous shaft speed and rated power at the drive end of the compressor.

7.3.4.2 Portable and skid-mounted compressors

The following additional markings shall be provided on the data plate:

— nominal power expressed in kilowatts (kW);

— mass of the most usual configuration, in kilograms (kg);

and, where appropriate:

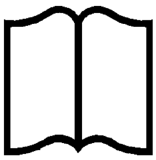
— maximum drawbar pull provided for at the coupling hook, in newtons (N);

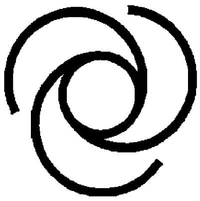
— maximum vertical load provided for on the coupling hook, in newtons (N).

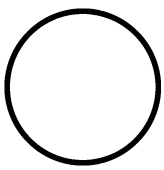
NOTE Portable compressor units used on-road are also subject to regulations related to motor vehicles and their trailers.

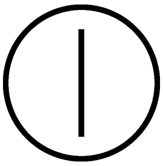
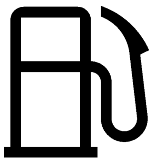
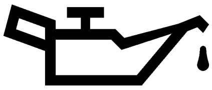
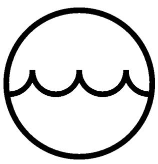
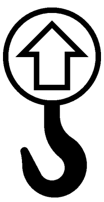
Annex A
(informative)

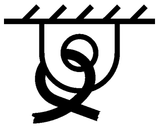
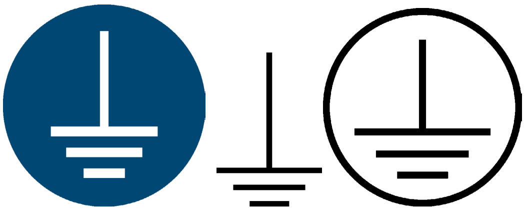
Graphical symbols

Graphical symbols	Reference	Colours of safety signs according to ISO 3864-1 and ISO 3864-4	Corresponding standard and registration number
A.1  	Mandatory action: Refer to instruction manual booklet Refer to instruction book, information; reading room, library	Background: blue Symbol: white	ISO 7010-M002 ISO 7000-0419
A.2 	Mandatory action: Wear ear protection	Background: blue Symbol: white	ISO 7010-M003

Graphical symbols	Reference	Colours of safety signs according to ISO 3864-1 and ISO 3864-4	Corresponding standard and registration number
A.3 	Prohibition: Do not start	Background: white Circular band: red Symbol: black	See EN 1012-1[a]
A.4 	Prohibition: Do not operate the portable compressor with the doors or enclosure open	Background: white Circular band: red Symbol: black	See EN 1012-1[a]
A.5  	Warning: Automatic start-up Automatic control (closed loop)	Background: yellow Triangular band: black Symbol: black	ISO 7010-W018 ISO 7000-0017
A.6  	Warning: Hot surface Caution, hot surface	Background: yellow Triangular band: black Symbol: black	ISO 7010-W017 IEC 60417-5041

Graphical symbols	Reference	Colours of safety signs according to ISO 3864-1 and ISO 3864-4	Corresponding standard and registration number
A.7 	Warning: Maintenance work in progress	Background: yellow Triangular band: black Symbol: black	See EN 1012-1[a]
A.8 	Warning: Exhaust of hot or harmful gases in normal working area	Background: yellow Triangular band: black Symbol: black	See EN 1012-1[a]
A.9 	Warning; Low temperature/freezing conditions	Background: yellow Triangular band: black Symbol: black	ISO 7010-W010
A.10	Start device		IEC 60417-5007
A.11 	Stop device		IEC 60417-5008

Graphical symbols	**Reference**	**Colours of safety signs according to ISO 3864-1 and ISO 3864-4**	**Corresponding standard and registration number**
A.12 	Start and stop device		IEC 60417-5010
A.13 	Emergency stop device	Red-coloured (mushroom-type push button on a yellow background)	IEC 60417-5638
A.14 	Direction of rotation	Symbol: black	ISO 7000-004
A.15 	Fuel fill	Symbol: black	ISO 7000-0245
A.16 	Oil fill	Symbol: black	ISO 7000-0248
A.17 	Coolant fill	Symbol: black	ISO 7000-0524
A.18 	Lifting point	Symbol: black	ISO 7000-1368

Graphical symbols	**Reference**	**Colours of safety signs according to ISO 3864-1 and ISO 3864-4**	**Corresponding standard and registration number**
A.19 	Lashing point (Tie down)		ISO 7000-2069
A.20 	Mandatory action: Connect an earth terminal to the ground Earth, ground Protective earth; protective ground		ISO 7010-M005 IEC 60417-5017 IEC 60417-5019
A.21 	Warning; Drop (fall)		ISO 7010-W008
A.22 	Warning; Crushing of hands		ISO 7010-W024

Graphical symbols	Reference	Colours of safety signs according to ISO 3864-1 and ISO 3864-4	Corresponding standard and registration number
A.23 	Warning; Explosive material		92/58/EWG ISO 7010-W002
A.24 	Warning; Flammable material		92/58/EWG ISO 7010-W021
A.25 	Warning; Toxic material		92/58/EWG ISO 7010-W016
A.26 	Warning; Magnetic field		92/58/EWG ISO 7010-W006
A.27 	Warning; Electricity		92/58/EWG ISO 7010-W012
A.28 	No access for unauthorized persons		92/58/EWG DIN 4844-2, D-P006

Graphical symbols	Reference	Colours of safety signs according to ISO 3864-1 and ISO 3864-4	Corresponding standard and registration number
A.29 	Do not exinguish with water		92/58/EWG ISO 7010-P011
A.30 	No open flame; Fire, open ignition source and smoking prohibited		92/58/EWG ISO 7010-P003
A.31 	Mandatory action: Wear eye protection		ISO 7010-M004
A.32 	Mandatory action: Wear respiratory protection		ISO 7010-M017
[a] This safety sign has not been internationally coordinated and registered.			

Additional symbols can be found in, e.g. ISO 7000, EN ISO 7010, IEC 60417 and DIN 4844-2.

Annex B
(informative)

Measure to ensure a safety function while testing a safety device (example)

B.1 Shutdown Override Switches

Machine protection systems shall only be equipped with shutdown override switches if tests of the protection system with ongoing machine operation are necessary to ensure availability of the process. During such a test, machine operation shall continuously be monitored by suitable personnel who will shut-down the machine immediately in case of danger. An operating mode selector switch (auto/maintenance) and an approval facility shall be provided for this purpose. The approval facility makes sure that only one protective circuit at a time is in test condition. For carrying out a test, the operating mode selector switch which is protected by a key or an access code has to be in the maintenance position. Switching over to the automatic mode immediately terminates any test in progress.

B.2 Monitoring

The presence of personnel for monitoring machine operation is ensured by actuation of the approval button. This is located in the close vicinity of a monitoring facility for continuous monitoring of the machine performance when a test is in progress. In case of danger it shall be possible to shut down the machine immediately from this point. The approval button has to be activated at regular intervals. At the latest 3 minutes after the last actuation, automatic machine protection becomes active again.

The position of the operating mode selector switch as well as active testing shall be indicated by an alarm and automatically recorded in an operating log.

Starting of the machine shall be interlocked when the operating mode selector switch is in maintenance position.

Override switches shall not be used for overriding such shutdown circuits whose required protection response is shorter than the usual response time of monitoring personnel (e.g. over-speed shutdown).

A manual emergency stop device shall only be overridden for testing if a second emergency-off device is active during this test and is located in the direct vicinity of the equipment to be tested. The inactive emergency-off device has to be marked accordingly when the test is in progress.

Annex C
(informative)

Guide to the application of current standards to the functional safety on safety related control of process compressors or compressor units

C.1 Introduction

This annex has been prepared to assist in the provision of safety related parts of control systems (SRP/CS), or safety instrumented systems (SIS) as they are hereafter referred to in this annex. Particular reference is made to the allocation of a suitable Safety Integrity Level (SIL) or Performance Level (PL). The specification of SIL and of PL has been excluded from the scope of this standard and, therefore, the compressor manufacturer is responsible for both the selection of suitable SIL or PL for the various safety functions involved and compliance with the associated specification in accordance with recognized standards.

Several standards are available for the design and validation of the safety related parts of control systems, each having a particular field of application. EN ISO 13849-1, EN ISO 13849-2 and EN 62061 are the recognized standards for the design and validation of the safety related parts of control systems for machinery in general. The seven parts of EN 61508 give generic requirements for all machinery and equipment, EN 62061 is a machinery specific standard within the framework of EN 61508 and EN 61511 is a process industry specific standard within the framework of EN 61508.

EN 62061 and EN ISO 13849-1 consider only safety related functions which operate in high demand mode. EN 61511 and EN 61508 consider safety related functions with high and/or low demand mode.

Most of the safety instrumented systems installed on process compressors or compressor units are typically considered to operate in low demand mode.

Because of the link between process compressors and process plant and the mode of operation of the safety function, the guidance in this annex is based on EN 61511 modified as necessary to accommodate the specific requirements of process compressors or compressor units.

Although the guidance in this annex is based on EN 61511, the standards EN ISO 13849-1, EN 62061, and/or EN 61508 may also be used where high demand mode is applicable.

C.2 Scope

This annex gives an overview of functional safety and describes the relevant lifecycle phases of safety instrumented systems forming part of the safety controls of process compressors or compressor units and provides guidance to the implementation of functional safety for process compressors or compressor units. The intention of this annex is to provide a basic overview of functional safety principles rather than a user guideline for specific applications.

C.3 Standard and code references

The following standards and codes are referenced in this annex.

C.3.1 International Electrotechnical Commission (IEC) / European Committee for Electrotechnical Standardization (CENELEC).

EN 61508, Parts 1 to 7	*Functional safety of electrical/electronic programmable electronic safety-related systems (IEC 61508)*
EN 61511, Parts 1 to 3	*Functional safety — Safety instrumented systems for the process industry sector (IEC 61511)*
EN 62061	*Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems (IEC 62061)*

C.3.2 International Organization for Standardization (ISO) / European Committee for Standardization (CEN).

EN ISO 13849-1	*Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design (ISO 13849-1)*
EN ISO 13849-2	*Safety of machinery — Safety-related parts of control systems — Part 2: Validation (ISO 13849-2)*

C.4 Standard abbreviations

The following abbreviations are commonly used throughout the standards for functional safety and this annex:

ALARP: As Low As Reasonably Practical

DC: Diagnostic Coverage

EUC Equipment Under Control

FR: Failure Rate

HFT: Hardware Fault Tolerance

IPL: Independent Protection Layer

MPS: Machine Protection Systems

MTBF: Mean Time Between Failure

PES: Programmable Electronic Systems

PFD: Probability of Dangerous Failure on Demand

PFD_{avg}: Average Probability of dangerous Failure on Demand

PFH: Average frequency of dangerous failure [h-1]

PL: Performance Level

RRF: Risk Reduction Factor

RFQ: Request for quotation

SFF: Safe Fail Fraction

SIF: Safety Instrumented Function

SIL: Safety Integrity Level

SIS: Safety Instrumented Systems

SRP/CS: Safety related part of a control system

C.5 Risk reduction process and functional safety

EN ISO 12100 defines risk as the combination of the probability of occurrence of harm and the severity of that harm. Within the risk assessment process all significant hazards should be identified and the resulting risk should be estimated. This estimated risk should be assessed by comparing each single risk with “tolerable risk” (see C.7.2.2). At first the risk assessment is carried out by assuming that risk reduction measures do not exist. As long as the risk exceeds the tolerable risk, risk reduction measures should be implemented until the residual risk is below the tolerable risk (see Figure C.1).

For a SIS where the SIL is determined using the risk graph at C.4, the risk may be considered tolerable when after the application of the appropriate values of S, F, A_v and W the system is in compliance with the indicated SIL or if "no additional safety requirements" is indicated.

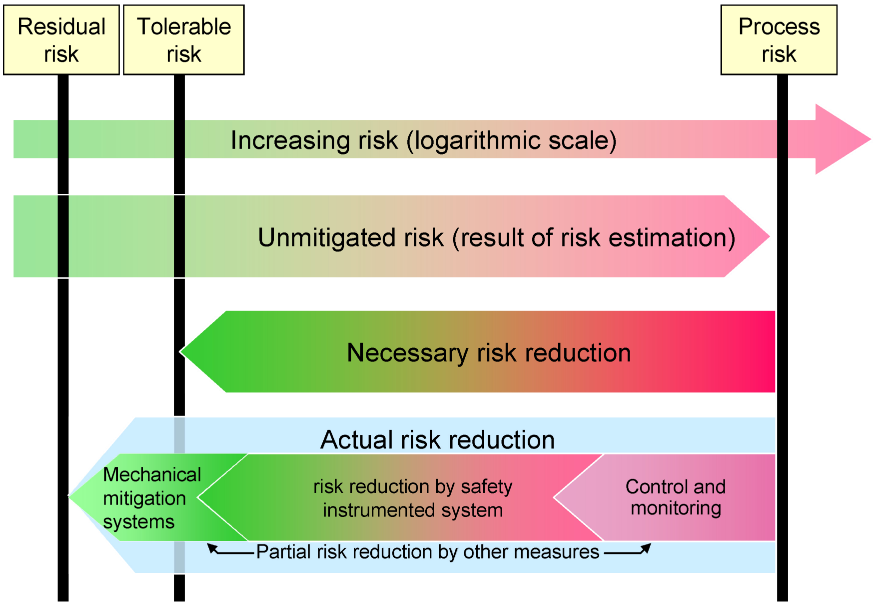


Figure C.1—Risk reduction process

The overall risk reduction can consist of different kinds of protective measures. When a SIS is used within the risk reduction process, the methods of functional safety should be implemented. The methods identified in EN 61508/EN 61511/EN 62061 are considering a quantitative risk reduction concept. According to these standards the risk is expressed as a quantifiable parameter which is allocated to a certain type of machinery or hazard.

The risk achieved after risk reduction should not exceed the tolerable risk.

The risk reduction by a SIS is identified as a risk reduction factor which is defined as the ratio of unmitigated to mitigated risk. The reciprocal value of the risk reduction factor is the minimum requirement for the functional reliability of a SIS and is expressed as PFD_{avg} (Average probability of a dangerous failure on Demand; see Table C.1 or Table C.7) or PFH (Average frequency of a dangerous failure [h-1]).

The standards EN 61508 and EN 61511 specify 4 levels and EN 62061 specifies 3 levels of safety performance for a safety function. Safety Integrity Level 1 (SIL 1) is the lowest level of safety integrity and safety Integrity Level 4 (SIL 4) is the highest level. Whereas EN ISO 13849-1 specifies 5 levels of safety performance for a safety function, these are called Performance Levels. Performance Level a (PL a) is the lowest level and Performance Level e (PL e) is the highest level.

As mentioned above the term PFD_{avg} is used to describe the risk reduction achieved. As can be seen from Table 1, a PFD value of 0.01 reduces the risk by 100 and falls into SIL 1. Risk reduction factors of more than 100 000 (SIL 4) are typically not seen in machinery applications and are not relevant for process compressors or compressor units.

Table C.1 contains the target failure measures for the SIL-Levels and the corresponding target risk reduction according to EN 61511-1:

Table C.1 — Target failure measures for a safety function operating in low demand mode of operation

Low demand mode of operation		
SIL-Level	Target average probability of failure on demand **PFD**	Target risk reduction
4	$\geq 10^{-5}$ to $<10^{-4}$	> 10 000 to ≤ 100 000
3	$\geq 10^{-4}$ to $< 10^{-3}$	> 1 000 to ≤ 10 000
2	$\geq 10^{-3}$ to $<10^{-2}$	> 100 to ≤ 1 000
1	$\geq 10^{-2}$ to $< 10^{-1}$	> 10 to ≤ 100

C.6 Relationship between EN 1012-3 and the standards for functional safety

Figure C.2 gives an overview between EN 1012-3, EN ISO 12100 and the functional safety standards.

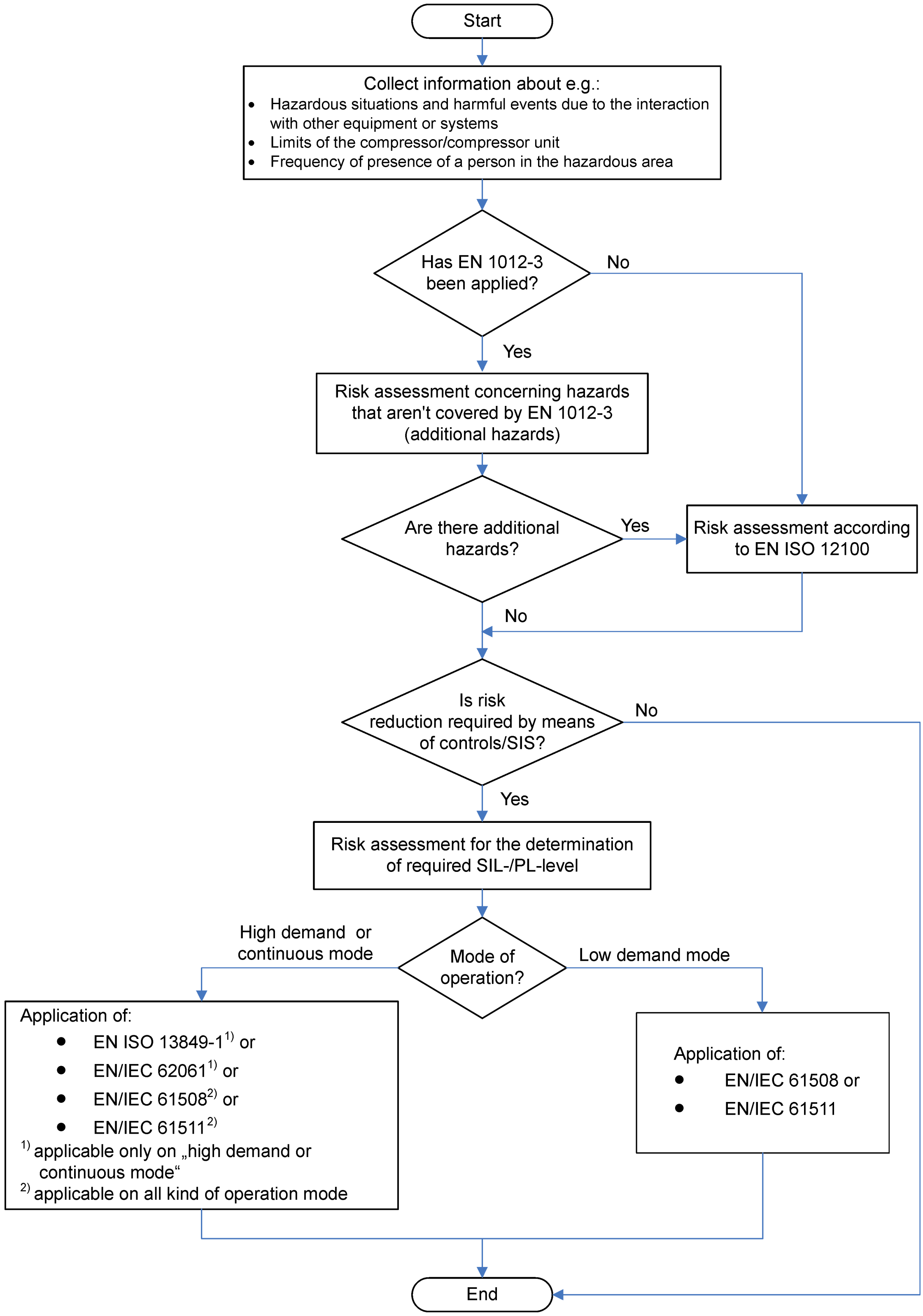


Figure C.2 — Relationship between the relevant standards

C.7 Process of functional safety

C.7.1 General

The model of a functional safety-process is shown in Figure C.3. This figure depicts all safety life-cycle phases of a safety instrumented system installed on a process compressor or compressor unit. For a manufacturer of process compressors or compressor units relevant phases begin with a risk assessment for the determination of the required SIL and ends with the installation, commissioning and validation of the safety instrumented system.

Operation, maintenance, modification and decommissioning are within the responsibility of the user of the compressor or compressor units. However, the manufacturer of the compressor or compressor units should provide all safety relevant information within the user manual supplied with the machine, particularly information concerning operation and maintenance.

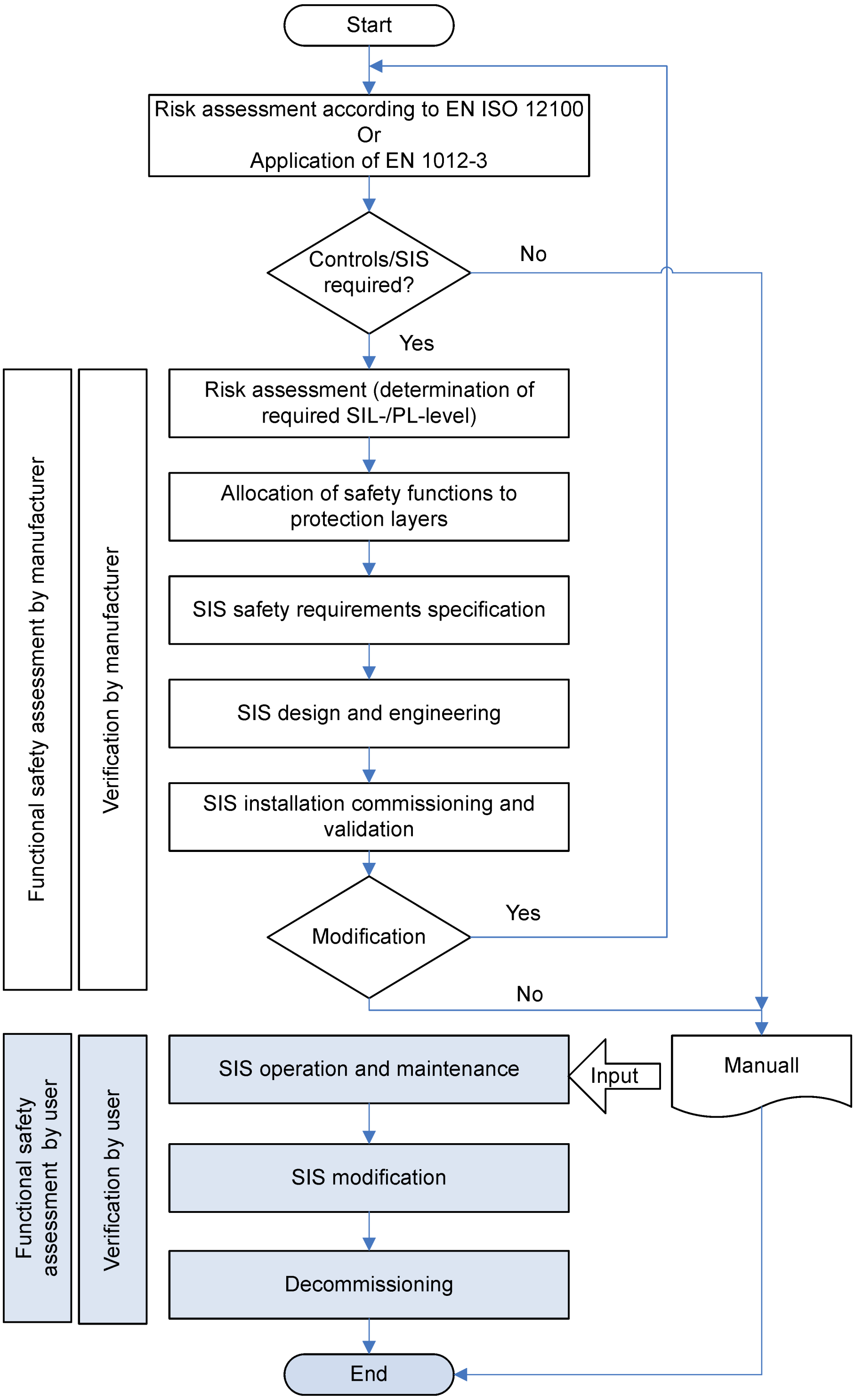


Figure C.3 — Safety life-cycle phases

C.7.2 Risk Assessment

C.7.2.1 General

For risk reduction using a SIS, a risk assessment should be carried out for the determination of the required SIL- or PL. During this risk assessment, all hazards should be identified and corresponding risks that should be reduced by the SIS should be assessed. Therefore, this assessment should be carried out by assuming that the considered SIS is not in place. The outcome of this assessment is the required SIL or PL.

The level of the required risk reduction by a SIS is dependent on the specific application of the process compressor or compressor unit. The level of the required risk reduction can vary and is dependant on, e.g. the type of compressor, operation range, the properties of the compressed gas. Therefore, a project specific risk assessment should be carried out.

The functional safety standards describe a number of methods for determining the required performance of the SIS. The most common methods are the risk graph, Layers of Protection Analysis (LOPA) and the risk matrix. The recommended approach is by the application of a calibrated risk graph or calibrated risk matrix. The calibrated risk graph for process compressors is given in Figure C.4.

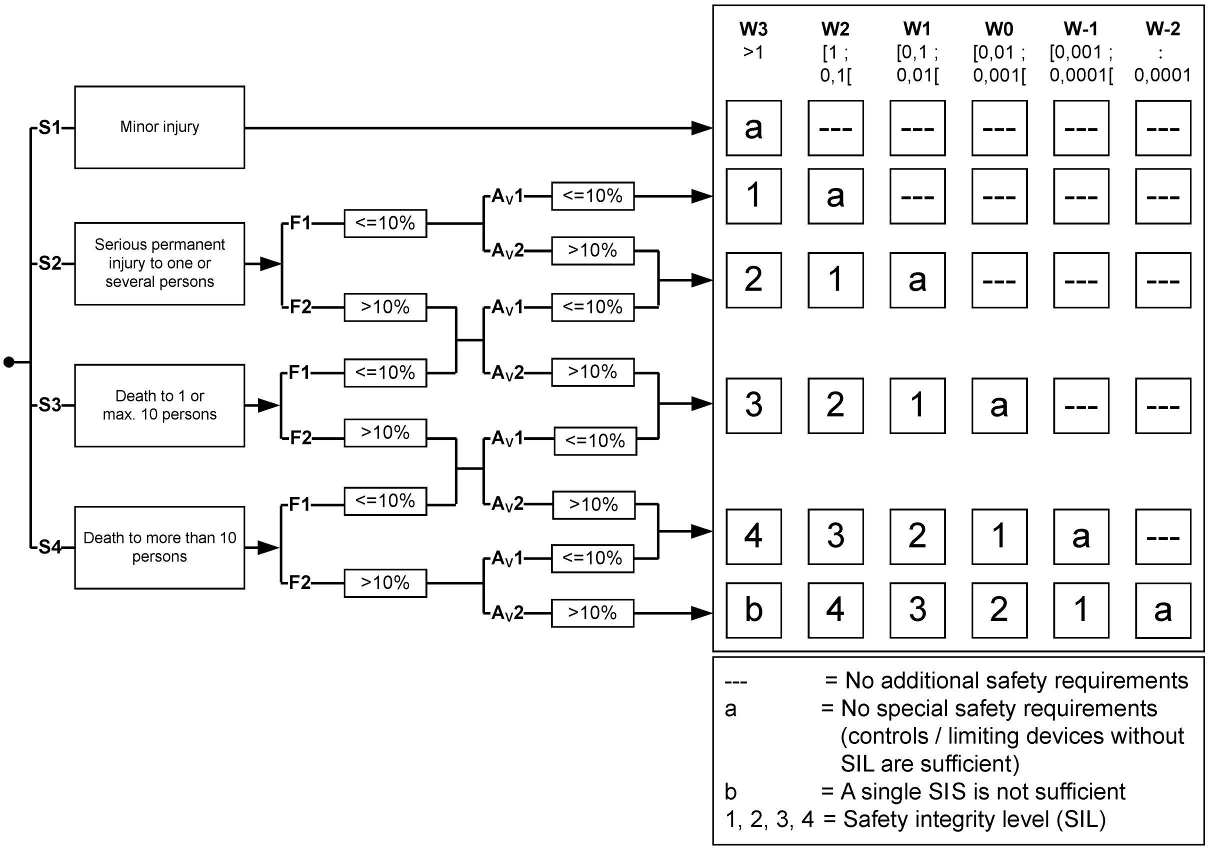


Figure C.4 — Calibrated risk graph for low demand mode

The determination of the required SIL using the risk graph method and Figure C.4 is achieved by the estimation of the following parameters:

Severity of the unwanted event (hazardous situation) – S (see C.7.2.2)

Probability of presence (probability that the exposed area is occupied) – F (see C.7.2.3)

Probability of the unavoidability of the unwanted event considering the vulnerability A_V (see C.7.2.4)

Probability of the occurrence of the unwanted event – W (see C.7.2.5)

C.7.2.2 Severity of the unwanted event – Parameter S

The parameter S is subdivided into four different categories, category 1 to category 4. Table C.2 below indicates the value of tolerable risk associated with each category.

Table C.2 — Definition of the range of the parameter Severity S and dedicated tolerable risk

Severity or consequence of risk – S			
Parameter	**Classification**	**Tolerable Risk [year]**	**Comments**
S1	Minor injury	1/100	First aid or medical care is required. No permanent injury
S2	Serious permanent injury to several persons; including death as a possible consequence of the injury	1/1 000	A clinical treatment is or a long recovery time is necessary. Due to the nature of the hazard death is not immediate and would be a consequence of serious injury.
S3	Death of 1 to 10 people	1/10 000	Death is immediate
S4	Death of more than 10 people	1/100 000	Highest risk

C.7.2.3 Probability of presence – Parameter F

The parameter F, as indicated in Table C.3, describes the probability of the presence of a person in the hazard zone at that time when the unwanted event happens (hazardous situation).

Table C.3 — Definition of the range of the parameter probability of presence in the hazard zone – F

Probability of presence in the hazardous zone – F		
Parameter	**Classification**	**Comments**
F1	≤10%	The hazardous area is occupied for ≤ 10 % of the time. F ≤ 10 % is typically relevant for hazardous events within a restricted hazardous area.
F2	>10%	This classification applies typically for hazards with large hazardous area. (e.g. for events where parts of the rotor can be ejected from the machine). F for all events which will only be detected if a person enters the hazardous area should be considered as F > 10 %. Examples: A jet from a high pressure system or areas contaminated by hazardous gases.

C.7.2.4 Probability of the unavoidability of the unwanted event considering the vulnerability – A_V

This parameter is dependent on two different factors which should be allocated a probability between 0 and 1. They are:

Parameter A: Unavoidability

This is the probability that the hazardous situation cannot be noticed or recognized in good time by the person in the hazardous area and that the occurrence of an unwanted event cannot be avoided through his own actions, e.g. escaping.

<u>The following should be taken into account when determining the factor A:</u>

- whether a hazardous situation could develop very quickly;
- recognition of the hazard without technical measures is not possible;
- existence of escape routes, etc.

Within this parameter it has to be estimated whether a person can recognize a hazardous event and avoid the consequence of this event (e.g. injury or death) by his own actions, e.g. escaping. Both, recognizing and avoiding, should be possible.

NOTE EN 61508/EN 61511 is using the parameter P (probability to avoid) which is the complement of A (P = 1-A)).

<u>Parameter V: Vulnerability</u>

The parameter V describes the probability that the expected category of severity of the unwanted event, e.g. S3 occurs provided that a hazardous event occurs, that a hazardous zone is occupied by persons and that these persons are not be able to avoid injury through their own actions.

<u>EXAMPLE 1</u> If the vicinity of the compressor or compressor unit is flooded with gas or steam, every person in the hazardous zone will be affected, the vulnerability would be 1.

<u>EXAMPLE 2</u> If the event is caused by a piece of material ejected from a shaft, the likelihood of a person in the hazardous area being injured is less than in example 1, and the vulnerability will be less than 1 by an amount dependant on the probability of contact.

From the two parameters A and V, the unavoidability A_V can be calculated from the following formula:

$$A_V = A \times V = (1-P) \times V \tag{C.1}$$

Table C.4 and Table C.5 give the characteristics of V, A, P and A_V.

Table C.4 — Characteristic of the parameter V, A, P and A_V

Parameter	**Definition**	**Character**	**Range**
V	Vulnerability	Probability	[0…1]
A	Unavoidability	Probability	[0…1]
P	Avoidability or probability to avoid the hazardous event	Probability	[1…0]
A_V	Unavoidability, considering the vulnerability	Probability	[0…1]

Table C.5 — Range of the Probability of the unavoidability of the unwanted event considering the vulnerability

Unavoidability A_V under consideration of vulnerability $\mathbf{A_V = A \times V = (1\text{-}P) \times V}$		
Parameter	**Definition**	**1.1.1 Comments**
A_V1	≤ 10 %	Probability that a hazardous event with occupied hazardous zone will lead to harm ≤ 10 %
A_V2	> 10%	Probability that a hazardous event with occupied hazardous zone will lead to harm > 10 %

C.7.2.5 Probability of the occurrence of the unwanted event – Parameter W

Number of hazardous events per unit time ("per year").The purpose of the W factor is to account for the frequency of the unwanted occurrence taking place without the addition of any safety-related systems. The assumption that the unwanted event may occur does not necessarily mean that the event actually happens (see Table C.6).

NOTE 1 This parameter W is also defined in EN ISO 12100:2010, 5.5.2.3.2 "Occurrence of a hazardous event".

Table C.6 — Definition of the range of the Probability of the occurrence of the unwanted event – W

Probability of the occurrence of the unwanted event – W		
Parameter	**Definition**	**Comments**
W3	> 1/year	The unwanted event may occur more than once per year.
W2	> 1/10 year ≤ 1/ year	The unwanted event may occur a maximum of once per year but more than once per 10 years.
W1	> 1/100 year ≤ 1/10 year	The unwanted event may occur a maximum of once per 10 years but more than once per 100 years.
W0	> 1/1 000 year ≤ 1/100 year	The unwanted event may occur a maximum of once per 100 years but more than once per 1 000 years.
W-1	> 1/10 000 year ≤ 1/1 000 year	The unwanted event may occur a maximum of once per 1 000 years but more than once per 10 000 years.
W-2	> 1/100 000 year ≤ 1/10 000 year	The unwanted event may occur a maximum of once per 10 000 years but more than once per 100 000 years.

NOTE 2 W0, W-1 and W-2 have been introduced to deal with hazards which while having a high level of severity the probability of occurrence is sufficiently low to make risk reduction unnecessary.

C.7.2.6 Risk reduction factor

The result of the risk estimation according to the calibrated risk graph shown at Figure C.4 is shown as either "a", "1" to "4", or "b". C.7 shows the estimated risk level, the corresponding risk reduction factors, probability of failure corresponding to the SIL-Level in case low demand mode of operation. However, Table C.7 does not contain any information about “b” which represents the highest risk and an E/E/PE safety related system is not sufficient. Such a high risk is considered as not relevant for compressor/compressor unit.

Table C.7— Risk Reduction Factor, probability of failure on demand and integrity level for low demand mode according to the calibrated risk graph

Risk level according to risk graph	Corresponding Risk Reduction Factor (RRF)	Corresponding Probability of failure on demand (PFD_{avg})	Corresponding Integrity Level
---	< 1	not relevant	not relevant
a	1 to 10	$\geq 10^{-1}$ to < 1	a
1	10 to 100	$\geq 10^{-2}$ to < 10^{-1}	SIL 1
2	100 to 1 000	$\geq 10^{-3}$ to < 10^{-2}	SIL 2
3	1 000 to 10 000	$\geq 10^{-4}$ to < 10^{-3}	SIL 3
4	10 000 to 100 000	$\geq 10^{-5}$ to <10^{-4}	SIL 4

C.7.2.7 Application of the risk graph on low demand mode of operation

The above depicts corresponding values of PFD_{avg} and hence the corresponding SIL in case of low demand mode of operation is calculated using following formula:

$$PFD_{avg} = 1/RRF$$

The application of the risk graph to high demand mode has not been considered within this annex because most of the safety instrumented systems installed on process compressors or compressor units are considered to operate in low demand mode. EN ISO 13849-1 and EN 62061 deal only with high demand mode and EN 61511 and EN 61508 deal with both low demand and high demand modes of operation (see Figure C.2). If a safety instrumented system is specified as high demand mode and the above specified method may be used, then further information is given in VDMA 4315-1.

C.7.3 Allocation of safety function to protection layers

The overall risk reduction can occur by simultaneous implementation of several protection measures. Each protection measure is called protection layer. To decide if a risk reduction by additional protection layers e.g. process control is required it is necessary to consider what kind of other protection layers exist (or need to exist) and how much protection they provide. As an example, the overall risk reduction can be achieved using one or several of the following systems:

— SIS, e.g. safety related control for pressure limiting system;

— other technology, e.g. safety valve, designing the equipment for maximum possible pressure;

— external risk reduction, e.g. physical distance, procedures for manual intervention or other organizational measure; fire walls or explosion pressure resistant equipment for fire and explosion hazards.

After this consideration a decision should be made whether a SIS is necessary and if it is an appropriate SIL should be determined - guidance is given in the respective standards.

C.7.4 Safety Requirements Specification

After allocation of the safety function to the protection layers the Safety Requirement Specification (SRS) should be developed. Within this document all aspects for the design of the required safety instrumented system should be defined and described. This document should contain the operation mode (low or high demand) the requirement for all required safety functions including, e.g. the architecture of the safety instrumented system, hardware, software. This document should include for example:

- an accurate specification for each safety function in terms of functionality and safety integrity;
- the Safety Integrity Level (SIL) for each safety function;
- a description of relevant process scenarios;
- response time requirements for the SIS to bring the process to a safe state;
- the test procedure for the validation test along with the acceptance criteria;
- required maximum interval between proof-tests;
- environmental conditions;
- organization or individuals responsibility chart (ref. EN 61508-1:2010, 6.2.1).

Details are given in the respective standards, e.g. EN 61511-1 and EN 61511-2.

This document (safety requirements specification) forms the basis of all activities within further phases of the safety life-cycle of the considered SIS.

C.7.5 Design and engineering

The design and engineering of the SIS should be carried out in accordance with the safety requirement specification. Guidance is given is given in respective standards, e.g. EN 61511-1 and EN 61511-2.

The design and engineering phase comprises the evaluation of the SIS concerning the verification of the achieved SIL. Within the evaluation there are three main types of requirements that have to be fulfilled in order to achieve a given SIL:

- the functional reliability of the SIS which is expressed by PFD or PFH (quantitative requirement);
- the architectural constrains of the SIS (qualitative requirements);
- techniques and measures are used avoiding and controlling systematic faults.

The PFD or PFH values should be obtained from the component supplier.

The requirements for architectural constraints consist of the following three parameters:

- the hardware fault tolerance of the SIS;
- safe failure fraction of the system detected by diagnostic test;
- the type of components of the SIS that are used, e.g. a sensor (type A or type B).

According to EN 61508-2 a component is considered as type A if:

- the failure modes of all constituent components are well defined; and

- the behaviour of the element under fault conditions can be completely determined; and
- there is sufficient dependable failure data to show that the claimed rates of failure for detected and undetected dangerous failures are met.

A component is considered as type B if:

- the failure mode of at least one constituent component is not well defined; or
- the behaviour of the element under fault conditions cannot be completely determined; or
- there is insufficient dependable failure data to support claims for rates of failure for detected and undetected dangerous failures.

The introduction of faults during the specification, design and development of the hardware and software operation or maintenance/testing of the SIS are considered as systematic faults. In order to avoid systematic faults certain measures and techniques should be adopted during the design phase.

The scope of the evaluation is dependent on the complexity and technique of the components used. There are different methods, the most common method is by calculation using the safety related parameters of the applied components of the SIS as far as they are available. In general, the following safety related parameters are used for the calculation:

- Operating mode
- Hardware fault tolerance – HFT
- Safe failure fraction – SFF
- Diagnostic Coverage - DC
- Mean time between failures – MTBF
- Mean time to repair – MTTR
- Average probability of dangerous failure on demand PFD_{avg} or average frequency of dangerous failure [h^{-1}] – PFH
- Total failure rate [h^{-1}] - λ
- Undetected dangerous failure rate [h-1] – λ_{DU}
- Detected safe failure rate [h-1] – λ_{SD}
- Detected dangerous failure rate [h-1] – λ_{DD}

The above-mentioned parameters should be obtained from the component supplier.

It is recommended to start the evaluation with a system function block diagram and then convert it into a reliability block diagram by deleting all those components which are not safety related. Afterwards, the available information about safety related parameter should be allocated to each component or function block of the SIS. Based on the information the SIL of the SIS should be calculated. The considered SIS has to meet the required SIL; this is dependent on several conditions:

- The probability of Failure on Demand (PFD_{avg}) of the entire loop should be lower than that required for the SIL. The higher the SIL, the lower the acceptable PFD_{avg}.

- For higher SIL, system containing redundancy is required. This is defined by the Hardware Fault Tolerance (HFT).

- Safe Failure Fraction (SFF) describes the fraction of safe and dangerous detected failures compared to all possible failures. The higher the SIL, the higher is the required SFF. A lower value of SFF can be compensated for by a higher HFT and vice versa.

- Proof Test Interval. During a Proof Test, the full functionality of a system should be verified.

If redundancy is used to improve functional safety, common cause failures should be considered. These are typically the most dominant factor during the SIL/PL evaluation. The probability of common cause failures is described by the factor ß.

Should the required safety related parameters not be fully available, they should be determined by analysis. There are different methods available e.g. fault tree analysis, event tree analysis, reliability block diagram or a Markov analysis. The methods are described in EN standards, see C.3 and the Bibliography).

If the verification shows that the actual achieved SIL is lower than that required, any or several of the above parameters should be improved and the safety requirement specification changed accordingly.

C.7.6 Installation commissioning and validation

C.7.6.1 General

After the realisation the SIS should be installed according to the specification and drawings and commissioned so that it is ready for final validation.

C.7.6.2 Installation and commissioning

All the required activities and responsibilities (persons, departments and organizations) should be defined within an installation and commissioning plan. In addition the plan should provide the procedures, measures and techniques to be used for installation and commissioning and when these activities should take place. Detailed information is given in respective standards, e.g. EN 61511-1 and EN 61511-2.

C.7.6.3 Validation

The designed SIS should be tested according to a validation or test plan. The scope, stage of the test, the conditions and criteria should be defined within the safety requirement specification. Should during the SIS during testing fail to meet the defined requirements, the documented safety requirement specification (SRS) should be modified, e.g. selection of redundant architecture or choosing other risk reduction measures and the process of functional safety should be started from the beginning.

The validation should also be planned; this plan should contain the definition and scheduling of activities, procedures, measures and techniques to be used for validation and the responsibilities.

C.7.7 Verification

Verification should be done after each process step according to the verification plan. In this plan all activities for each lifecycle phase should be determined. The verification should include a checking process to establish that the defined activities are completed and the outcomes satisfy the defined requirements for the appropriate phases.

C.7.8 Assessment of functional safety

Within the assessment of functional safety it should be established that the SIS meets all defined requirements concerning function and safety integrity. The assessment of functional safety should be carried out according to a plan in such a way that a judgement can be made as to the functional safety and safety integrity achieved by the safety instrumented system.

The plan should contain at least the following information:

— definition of the functional safety assessment stage (time schedule);

— allocation of responsibilities;

— definition of required qualification (the skills, responsibilities and authorities) of the person or team, who carried out functional safety assessment;

— the level of independence of the assessment team or person;

— definition of the scope of the functional safety assessment.

Detailed information is given in respective standards, e.g. EN 61508-1, EN 61511-1.

EN 61511 recommends estimation is carried out after the following stages (see Figure C.5):

— Stage 1: the risk assessment has been carried out, the required protection layers have been identified and the safety requirement specification has been developed;

— Stage 2: the safety instrumented system has been designed;

— Stage 3: the installation, pre-commissioning and final validation of the safety instrumented system has been completed and operation and maintenance procedures have been developed;

— Stage 4: gaining experience in operating and maintenance;

— Stage 5: modification and prior to decommissioning of a safety instrumented system.

A functional safety assessment can only be carried out by a manufacturer of a process compressor or compressor unit within Stages 1 to 3.

C.8 Risk assessment of compressor and auxiliary system

The required SIL or PL of a safety related control depends on the risk level that has to be avoided or limited by this control. In case of compressors or compressor units the level of risk may vary depending on type, size or/and application of a compressor or compressor unit. As an example, the level of risk caused by mechanical hazards increase with increasing size of the compressor or compressor unit. This indicates that with increasing size there is a requirement to apply a specific SIL, whereas with decreasing size a SIL-Level may not be required. A similar situation exists with respect to the type of gas processed as the level of risk increases due to the hazard associated with the gas increases, e.g. toxicity or explosiveness.

As a result of the conditions identified above it is not possible to determine a specific SIL/PL for all required safety related controls of a compressor or compressor unit without taking into account the different dependencies that affect the required SIL-Level. Therefore, it is recommended to determine the required SIL-/PL-Level of each safety related control by carrying out a risk assessment considering all situations such as type of compressor, application, and conditions of the site of installation, which may affect the results.

— Further guidance for the determination of the SIL of different safety related controls installed in compressor units is available within the VDMA 4315 (see Bibliography).

As mentioned above the required SIL-Level of a SIS installed in a process compressor or compressor units is dependent on its actual application. It is recommended to consider the risk assessment according to VDMA 4215 Parts 5 to 7 as guidance for the application specific risk assessment.

C.9 Responsibilities

C.9.1 End user and manufacturer

The compressor or compressor unit manufacturer determines the required SIL/PL by developing a risk assessment. However, in general the end user also carries out a risk assessment for the safety of the plant that includes the effect of the compressor(s) and compressor unit(s) on the safe operation of the plant. In the risk assessment and associated SIL/PL evaluation, both parties should follow EN 61508, EN 61511 or another appropriate standard in accordance with C.1.

The manufacturer should ask for sufficient information from the end user for the final determination of the required degree of risk reduction and for the specification of the required SIL/PL for each protection loop of the compressor or compressor unit.

The manufacturer should ask the end user for the shortest acceptable proof test interval, consistent with safe operation, for those tests which affect the process. Partial stroke tests or other proof tests which have only minor effect on the process may be performed more frequently.

C.9.2 Compressor or compressor unit manufacturer

The safety related equipment supplier should provide all the necessary data which is required by the end user and compressor manufacturer for their risk assessments and SIL/PL evaluation.

This shall include:

— probability of Failure on Demand for each subsystem (PFD; PFH);

— hardware fault tolerance HFT;

— safe Failure Fraction SFF;

— diagnostic Coverage;

— mean Time to dangerous failure $MTTF_D$;

— mean Time to Repair MTTR.

This information should be sufficient to allow the end user to perform a SIL/PL evaluation based to verify that the entire loop meets all functional safety requirements.

If the risk analysis of the end user and the compressor manufacturer results in differing needs for the required SIL/PL, then the highest requirement should govern.

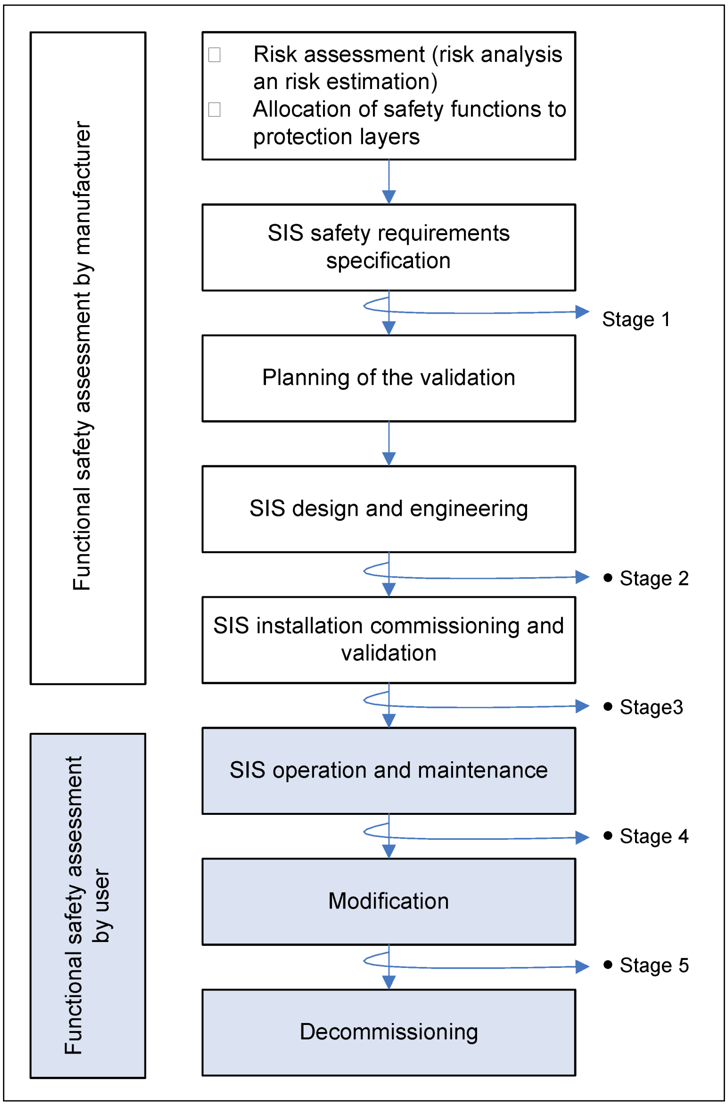


Figure C.5 — Functional safety assessment

The number, size and scope of functional safety assessment activities should depend upon the specific circumstances. The factors in this decision are likely to include:

— size of project;

— degree of complexity;

— safety integrity level;

— duration of project;

— consequence in the event of failure;

— degree of standardization of design features;

— safety regulatory requirements;

— previous experience with a similar design.

C.9.3 Example 1, using EN 61508, EN 61511

C.9.3.1 General

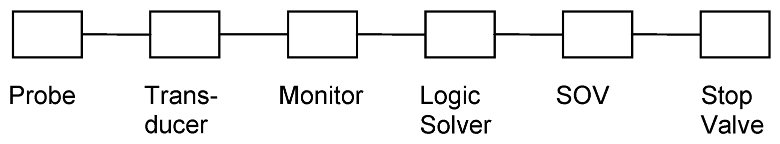


Figure C.6 — Example of typical protection loop

This diagram shows a typical protection loop, consisting of Probe, Transducer, Monitor, Logic Solver, Solenoid Valve and Stop Valve. It can represent a Shaft vibration loop, a single channel axial displacement loop, a temperature loop with local temperature transmitter as well a single channel overspeed loop.

This loop is evaluated as per EN 61511.

C.9.3.2 Using of calibrated risk graph

An example of a risk assessment using the risk graph as per C.7.2 should be given. The risk under investigation is the loop above. The severity of unwanted event may be serious injury.

The consequence is thus S2.

The frequency of exposure time is assumed to be more than 10 % (for more than 10 % of the total operation time, a person is located in a section where the unwanted event may harm a person), thus F = F2.

In general for the determination of the probability of unavoidability (A) under consideration of vulnerability (V) a separate estimation of the unavoidability and vulnerability is necessary. The multiplication of the A and V yields A_V (A_V = A x V; see C.7.2.4). The probability of unavoidability (A) depends on different situations such as the development of the hazardous situation (fast or slow), whether it is cognisable and whether there are possibilities to avoid that hazard. The probability of vulnerability depends on the characteristic of that hazard presented, e.g. punctiform like hot surface or extensive like explosion or contaminated area. The vulnerability in the case of a hot surface is very small and in case of an explosion very high. As this cannot be fully determined, a conservative assumption A_V2 is made (the probability that the event may harm a person is higher than 10 %).

It is assumed that such an event may happen between once per year and once in 10 years (W = W2).

The risk graph shows SIL 2 for this risk.

NOTE If the machine room is occupied only occasionally (less than 10 % of the total operation time), F can be selected to F1. This leads to SIL 1. The same applies if the probability that the unwanted event happens is less than once in ten years (W = W1).

C.9.3.3 SIL evaluation as per EN 61511/EN 61508

C.9.3.3.1 General

The design engineer selected a 1oo1 architecture with one sensor per plane and a simplex logic solver and a single SOV.

The equipment vendor provides the following data.

Input system:

- PFD_{avg} per probe and transducer PFD_{avg} = 2.56E-4
- Safe Failure Fraction SFF = 0.65
- Type A components (non-complex)

Logic Solver:

- PFD_{avg} for the monitoring system PFD_{avg} = 1.58E-3
- PFD_{avg} for logic solver PFD_{avg} = 1.70E-4
- Safe Failure Fraction SFF = 0.95
- Type B components (complex)

Output subsystem:

- PFD_{avg} for trip solenoid valve PFD_{avg} = 8.72E-3
- PFD_{avg} for stop valve PFD_{avg} = 3.75E-3
- Safe Failure Fraction SFF = 0.62
- Type A components (non-complex)

Common data for all parts:

- Hardware fault tolerance HFT = 0
- Proof Test Interval = 2 years
- Mean Time to Repair MTTR = 8 h

C.9.3.3.2 Probability of dangerous failure

The PFDavg calculation provides PFDavg = 1.45E-2 for the complete safety loop.

This figure is higher than the acceptable 1E-2 (10-2) for SIL 2. This system may be used as SIL 1 only.

2.56E-4	PFDavg Probe and Transducer
1.58E-3	PFDavg Monitor
1.70E-4	PFDavg Logic
8.72E-3	PFDavg SOV
3.75E-3	PFDavg Stop Valve
1.45E-2	PFDavg, Example1

C.9.3.3.3 Architectural constraints

Input subsystem

Probe and transducer are both type A components (non-complex), so the architectural constraints according to EN 61508-2:2010, Table 2, allow a maximum rating of SIL 2, due to SFF > 60 % at HFT = 0.

Logic solver subsystem

Monitor and Logic Solver are both type B components (complex), so their architecture is evaluated according to EN 61508-2:2010, Table 3. The safe failure fraction SFF = 95 % and hardware fault tolerance HFT = 0 allow a maximum rating of SIL 2.

Output subsystem

Solenoid valve and stop valve are non-complex type A components. SFF = 62 % and HFT = 0 allow a maximum rating of SIL 2.

Result per EN 61511/EN 61508

Probability of failure (PFDavg) for the complete safety loop restricts the safety function to a maximum rating of SIL 1.

Architectural constraints (SFF and HFT) for all subsystems would allow up to SIL 2.

There are different measures available to increase the degree of risk reduction, e.g. shorten the proof test interval, selection of components with lower probability to fail, or install redundancy.

The trip solenoid is the weakest item in the loop and thus easiest improvement can be made by putting 2 solenoids in parallel. This is discussed in example 2.

C.9.4 Example 2, using EN 61508, EN 61511

The risk assessment for a loop shown in example 1 resulted in a required SIL 2 if the machine room is frequently occupied by persons.

The design engineer selected a 1oo1 architecture with one sensor per plane and a simplex logic solver, but redundant solenoid valves (see Figure C.7).

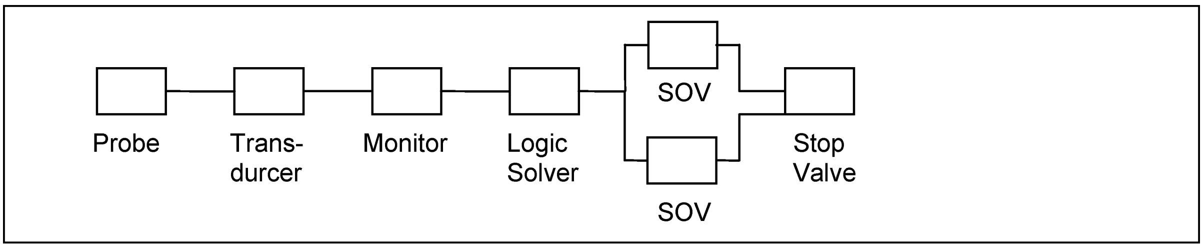


Figure C.7 — 1oo1 architecture

The equipment vendor provided the same data as for Example 1.

For the calculation of the PFDavg for the two solenoid valves, a common cause factor ß = 0.05 (typical value) is estimated. This gives a PFDavg of 6.72E-3 for the loop with two parallel solenoids which is within the required range for SIL2 as per Table C.1.

Since the architectural constraints of example 1 already met the requirements of SIL 2, the higher fault tolerance in Example 2 will only improve on it.

2.56E-4	PFD_{avg} Probe and Transducer
1.58E-3	PFD_{avg} Monitor
1.70E-4	PFD_{avg} Logic
5.12E-4	PFD_{avg} SOV, 1oo2 fault tolerant
3.75E-3	PFD_{avg} Stop Valve
6.27E-3	PFD_{avg}, Example2

The requirements of functional safety are met.

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Directive (2006/42/EC).

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the normative clauses of this standard confers, within the limits of the scope of this standard, a presumption of conformity with the relevant Essential Requirements except Essential Requirement 1.2.1, as it relates to the specification of performance levels and/or safety integrity levels, of that Directive and associated EFTA regulations.

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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