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Proof of competence of hydraulic cylinders in crane applications

Vérification d’aptitude des vérins hydrauliques pour appareils de levage

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Foreword

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

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

This document was prepared by Technical Committee ISO/TC 96, *Cranes*, Subcommittee SC 10, *Design principles and requirements*.

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

Proof of competence of hydraulic cylinders in crane applications

1 Scope

This document applies to hydraulic cylinders that are part of the load carrying structure of cranes. It is intended to be used together with the ISO 8686 series and ISO 20332, and as such they specify general conditions, requirements and methods to prevent mechanical hazards of hydraulic cylinders, by design and theoretical verification.

This document does not apply to hydraulic piping, hoses, connectors and valves used with the cylinders, or cylinders made from other material than (carbon) steel.

2 Normative references

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

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 683-1, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Non-alloy steels for quenching and tempering·*

ISO 683-2, *Heat-treatable steels, alloy steels and free-cutting steels — Part 2: Alloy steels for quenching and tempering*

ISO 724, *ISO general-purpose metric screw threads — Basic dimensions*

ISO 5817:2014, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

ISO 8492, *Metallic materials — Tube — Flattening test*

ISO 8686 (all parts), *Cranes — Design principles for loads and load combinations*

ISO 12100, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 20332:2016, *Cranes — Proof of competence of steel structures*

EN 10277:2018, *Bright steel products — Technical delivery conditions — Part 2: Steels for general engineering purposes*

EN 10297-1, *Seamless circular steel tubes for mechanical and general engineering purposes — Technical delivery conditions — Part 1: Non-alloy and alloy steel tubes*

EN 10305-1, *Steel tubes for precision applications — Technical delivery conditions — Part 1: Seamless cold drawn tubes*

EN 10305-2, *Steel tubes for precision applications — Technical delivery conditions — Part 2: Welded cold drawn tubes*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbols	Description
$A\%$	Percentage elongation at fracture
a	Weld throat thickness
A_i, B_i, C_i, D_i	Constants
A_s	Stress area
D	Piston diameter
d	Rod diameter
$D_{a,i}$	Axles diameter
D_p	Pressure affected diameter
D_w	Weld diameter
E	Modulus of elasticity
F	Compressive force
F_A	Compressive force
FE	Finite elements
f_{Rd}	Limit design stress
$f_{Rd\sigma}$	Limit design stress, normal
$f_{Rd\tau}$	Limit design stress, shear
F_S	Lateral force
F_{Sd}	External compressive design force
$f_{w,Rd}$	Limit design weld stress
f_y	Yield strength
h	thickness of the cylinder bottom
I	Moment of inertia, generic
I_1	Moment of inertia of the tube
I_2	Moment of inertia of the rod
L	Overall length of the cylinder
L_1	Length of the cylinder tube
L_2	Length of the piston rod
m	Slope of the log $\Delta\sigma$ – log N curve
M_0	Shell section bending moment, acting at the intersection between tube and bottom
M_b	Bending moment
N	Compressive force
N_k	Critical buckling load
N_{Rd}	Limit compressive design force
p_{i1}	Maximum pressure in piston side chamber
p_{i2}	Maximum pressure in rod side chamber

Table 1 *(continued)*

Symbols	Description
p_o	Outer pressure
p_{Sd}	Design pressure
R	Middle radius of the tube ($R = r_i + t/2$)
r_i	Inner radius of the tube
r_o	Outer radius of the tube
r_r	Outer radius of the piston rod
s_3	Stress history parameter (see ISO 20332)
t	Wall thickness of the tube
T_0	Shell section transverse force, acting at the intersection between tube and bottom
x, y	Longitudinal and lateral coordinates
α	Angular misalignment, radians
γ_m	General resistance factor (γ_m = 1,1, see ISO 8686-1)
γ_{mf}	Fatigue strength specific resistance factor (see ISO 20332)
γ_R	Total resistance factor ($\gamma_R = \gamma_m \times \gamma_s$)
γ_s	Specific resistance factor
$\Delta\sigma$	Stress range
$\Delta\sigma_b$	Bending stress range in the tube
$\Delta\sigma_c$	Characteristic fatigue strength
$\Delta\sigma_m$	Membrane stress range in the tube (axial)
$\Delta\sigma_{Rd}$	Limit design stress range
$\Delta\sigma_{Sd}$	Design stress range
Δp_{Sd}	Design pressure range on piston side
δ_{max}	Maximum displacement
κ	Reduction factor for buckling
λ	Slenderness
λ_i	Friction parameters
μ_i	Friction factors
ν	Poisson's ratio (ν = 0,3 for steel)
σ_a	Axial stress in the tube
σ_b	Lower extreme value of a stress range
σ_r	Radial stress in the tube
σ_{Sd}	Design stress, normal
$\sigma_{w,Sd}$	Design weld stress, normal
σ_t	Tangential stress in the tube (hoop stress)
σ_u	Upper extreme value of a stress range
τ_{Sd}	Design stress, shear
$\tau_{w,Sd}$	Design weld stress, shear

5 General

5.1 Documentation

The documentation of the proof of competence shall include:

— design assumptions including calculation models;

— applicable loads and load combinations;

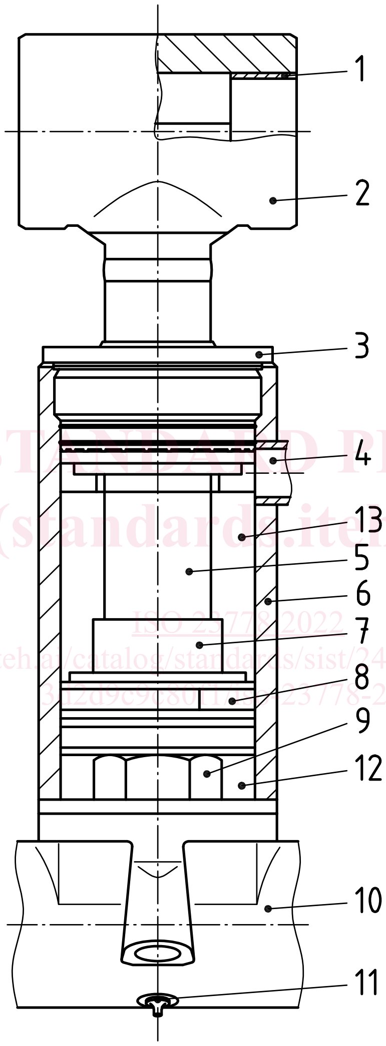
— material grades and qualities;

— weld quality levels, in accordance with ISO 5817 and ISO 20332;

— relevant limit states;

— results of the proof of competence calculation, and tests when applicable.

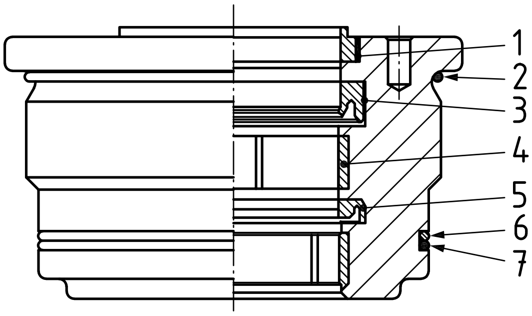
The main parts of hydraulic cylinder are indicated in Figure 1 to Figure 3.



Key

1	bushing
2	rod head
3	cylinder head
4	oil connector
5	piston rod
6	cylinder tube
7	spacer
8	piston
9	nut
10	cylinder bottom
11	grease nipple
12	piston side chamber
13	rod side chamber

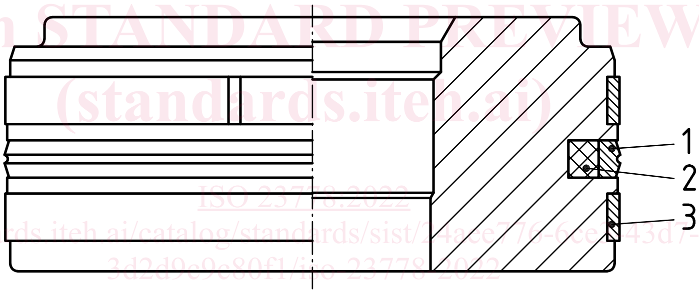
Figure 1 — Complete cylinder



Key

1 wiper
2 O-ring
3 secondary seal
4 guide ring (2 ×)
5 primary seal
6 backup ring
7 O-ring

Figure 2 — Cylinder head



Key

1 seal
2 pressure element
3 guide ring (2 ×)

Figure 3 — Piston

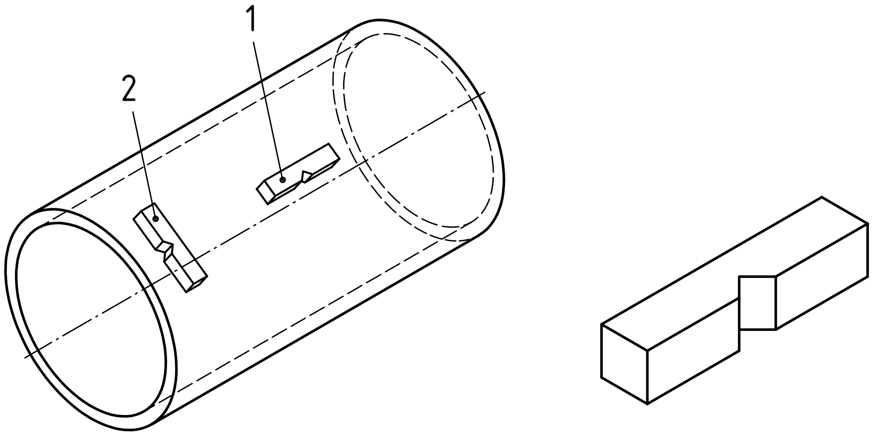
Figures 1 to 3 show some typical design features. Other designs may be used.

5.2 Materials for hydraulic cylinders

5.2.1 General requirements

The materials for load carrying cylinder tubes and piston rods shall fulfil the following requirements:

— The impact toughness in the transversal direction shall be tested in accordance with ISO 148-1 and shall meet the requirements stated in ISO 20332. Samples shall be cut out in the longitudinal direction. For cylinder tubes and pressurized piston rods, samples shall also be cut out in the transversal direction. The samples shall be prepared such that the axis of the notch is perpendicular to the surface of the tube.



Key

1 sample cut out in longitudinal direction

2 sample cut out in transversal direction

Figure 4 — Sample for impact toughness testing

— If the material thickness does not allow samples to be cut out in the transversal direction, the tube material shall pass a flattening test in accordance with ISO 8492. For welded tubes, two tests are required; one with the weld aligned with the press direction and one where the weld is placed 90° from the press direction, see Figure 4. The tube section shall be flattened down to a height *H* given by:

$$H = \frac{1{,}07 \cdot t}{C + \frac{t}{D_\mathrm{o}}}$$

where

C	is a factor that depends on the yield strength of the material,
	C is 0,07 for $f_y \leq 400$ MPa and C is 0,05 for $f_y > 400$ MPa;
D_o	is the outer diameter of the tube;
t	is the wall thickness of the tube.

Material used in other parts shall meet the requirements specified in ISO 20332.

5.2.2 Grades and qualities

Steels in accordance with the following standards shall preferably be used as material for cylinder tubes and piston rods:

— ISO 683-1;

— ISO 683-2;

— EN 10277:2018;

— EN 10297-1:

— EN 10305-1;

— EN 10305-2.

Alternatively, other steel grades and qualities than those listed in this subclause may be used as material for cylinder tubes and piston rods, provided that the following conditions apply:

— the design value of f_y is limited to $f_u/1{,}1$ for materials with $f_u/f_y < 1{,}1$;

— the percentage elongation at fracture A % ≥ 14 % on a gauge length $L_0 = 5{,}65 \times \sqrt{S_0}$ (where S_0 is the original cross-sectional area).

Grades and qualities of materials used in other parts of cylinders or mounting interfaces of cylinders shall be selected in accordance with ISO 20332.

6 Proof of static strength

6.1 General

A proof of static strength by calculation is intended to prevent excessive deformations due to yielding of the material, elastic instability and fracture of structural members or connections. Dynamic factors given in the relevant part of ISO 8686 are used to produce equivalent static loads to simulate dynamic effects. Also, load increasing effects due to deformation shall be considered. The theory of plasticity for calculation of ultimate load bearing capacity is not considered acceptable for the purposes of this document. The proof shall be carried out for structural members and connections while taking into account the most unfavourable load effects from the load combinations A, B or C in accordance with the relevant part of ISO 8686 or relevant product standards.

This document considers only nominal stresses, i.e. those calculated using traditional elastic strength of materials theory; localized stress concentration effects are excluded. When alternative methods of stress calculation are used such as finite element analysis, using those stresses directly for the proof given in this document can yield inordinately conservative results as the given limit states are intended to be used in conjunction with nominal stresses.

Cylinder actions are either active or passive. The action is active when the force from the cylinder exerts a positive work on the crane structure, elsewise the action is passive.

As the forces applied to the cylinder by the crane structure are computed in accordance with ISO 8686, they are already increased by the partial safety factors γ_p and relevant dynamic factors. Formula (1) and Formula (2) give design pressures p_{Sd} caused by forces acting on the cylinder from the crane structure. In addition, additional pressures p_{Sde} caused by internal phenomena in the hydraulic circuit shall be considered and added to the design pressures p_{Sd}. Such internally generated pressures can be caused, for example, by regenerative connections, pressure drop in return lines or cushioning.

In case a cylinder is intended to be tested as a component at higher pressure than the design pressure p_{Sd}, this load case shall also be taken into account in the proof of static strength, and in which case the test pressure shall be multiplied by a partial safety factor γ_p equal to 1,05.

The design pressure p_{Sd} in the piston side chamber or in the rod side chamber shall be computed from the design force F_{Sd} taking into account the force direction and the cylinder efficiency η due to friction. An efficiency factor Ψ is used to handle the effect of cylinder friction. For active cylinders Ψ has the value of $1/\eta$ and for passive cylinders Ψ has the value of η.

For the piston side chamber, the design pressure is given by Formula (1):

$$p_{Sd} = \frac{4 \cdot F_{Sd}}{\pi \cdot D^2} \cdot \Psi \tag{1}$$

where

F_{Sd} is the external design force;

D is the piston diameter;

Ψ is set to η for passive cylinders and to $1/\eta$ for active cylinders.

For the rod side chamber, the design pressure is given by Formula (2):

$$p_{Sd} = \frac{4 \cdot F_{Sd}}{\pi \cdot \left(D^2 - d^2\right)} \cdot \Psi + p_{Sde} \tag{2}$$

where

F_{Sd} is the external design force;

D is the piston diameter;

d is the rod diameter;

Ψ is set to η for passive cylinders and to $1/\eta$ for active cylinders;

p_{Sde} is additional pressure caused by internal phenomena (e.g. regeneration).

Unless justified value of the efficiency η is available and used, Ψ shall be assigned the value of 1,1 for active cylinders and the value of 1,0 for passive cylinders.

6.2 Limit design stresses

6.2.1 General

The limit design stresses f_{Rd} shall be calculated from Formula (3):

$$f_{Rd} = f_n \left(f_k , \gamma_R \right) \tag{3}$$

where

f_n is a general function as described in 6.2.2;

f_k is the characteristic values (or nominal value);

γ_R is the total resistance factor.

6.2.2 Limit design stress in structural members

The limit design stress f_{Rd}, used for the design of structural members, shall be calculated from Formulae (4) and (5):

$$f_{Rd\sigma} = \frac{f_y}{\gamma_{Rm}} \text{ for normal stresses} \tag{4}$$

$$f_{Rd\tau} = \frac{f_y}{\gamma_{Rm} \cdot \sqrt{3}} \text{ for shear stresses} \tag{5}$$

with $\gamma_{Rm} = \gamma_m \cdot \gamma_{sm}$

where

f_y is the minimum value of the yield stress of the material;

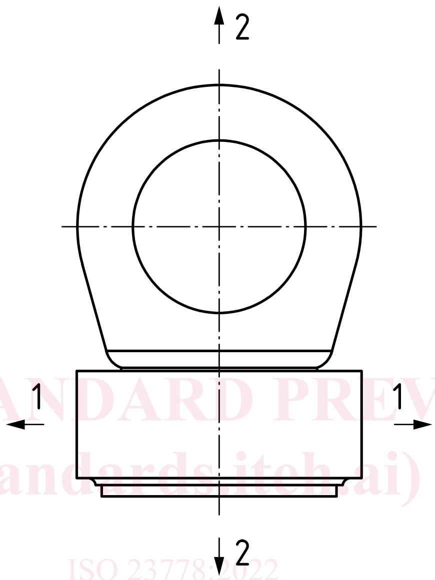
γ_m is the general resistance factor $\gamma_m = 1{,}1$ (see ISO 8686-1);

γ_{sm} is the specific resistance factor for material in accordance with ISO 20332;

γ_{sm} = 0,95 is the basic value for material not loaded perpendicular to the rolling plane.

For tensile stresses perpendicular to the plane of rolling (see Figure 5), the material shall be suitable for carrying perpendicular loads and be free of lamellar defects. ISO 20332 specifies the values of γ_{sm} for material loaded perpendicular to the rolling plane.

Figure 5 provides an example of a cylinder tube bottom where plate steel is used (eye is welded) and shows a tensile load perpendicular to plane of rolling.



Key

1 plane of rolling

2 direction of stress/load

Figure 5 — Tensile load perpendicular to plane of rolling

6.2.3 Limit design stresses in welded connections

The limit design weld stress $f_{w,Rd}$ used for the design of a welded connection shall be in accordance with ISO 20332.

6.3 Linear stress analysis

6.3.1 General

Subclause 6.3 comprises typical details for consideration that may be relevant for the proof of static strength. Details that are only relevant for fatigue analysis (e.g shell bending of tube) are not dealt with in 6.3. For cases or conditions not covered here, other recognized sources or static pressure/force testing may be used.

6.3.2 Typical cylinder arrangements

Before executing calculations, boundary conditions and loading shall be investigated. Typical conditions to be determined are:

— external forces and directions;