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Hydraulic fluid power — Cylinders — Method for determining the buckling load

Transmissions hydrauliques — Vérins — Méthode de détermination du flambage

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed every three years with a view to deciding whether it can be transformed into an International Standard.

Attention is drawn to the possibility that some of the elements of this Technical Specification may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 13725 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 3, *Cylinders*.

Introduction

Historically, cylinder manufacturers in the fluid power industry have experienced very few rod buckling failures, most likely due to the conservative factors of safety employed in the designs and factors of safety recommended to their users. Many countries and some large companies have developed their own methods for determining the buckling load.

The method presented in this Technical Specification has been developed to comply with the requirements formulated by ISO working group TC 131/SC 3/WG 1 during their meeting of November 1995.

Hydraulic fluid power — Cylinders — Method for determining the buckling load

1 Scope

This Technical Specification specifies a method for the determination of buckling load which

a) takes into account the complete geometry of the fluid power cylinder, meaning it does not treat the fluid power cylinders as an equivalent bar,

b) can be extended to be used for all types of cylinder mounting and rod end connection,

c) includes a factor of safety, k, to be determined by the person performing the calculations and reported with the results of the calculations,

d) takes into account a possible off-axis loading,

e) takes into account the weight of the fluid power cylinder, meaning it does not neglect all transverse loads applied on the fluid power cylinder,

f) can take into account a misalignment, but only if it is situated in the plane of cylinder selfweight, and

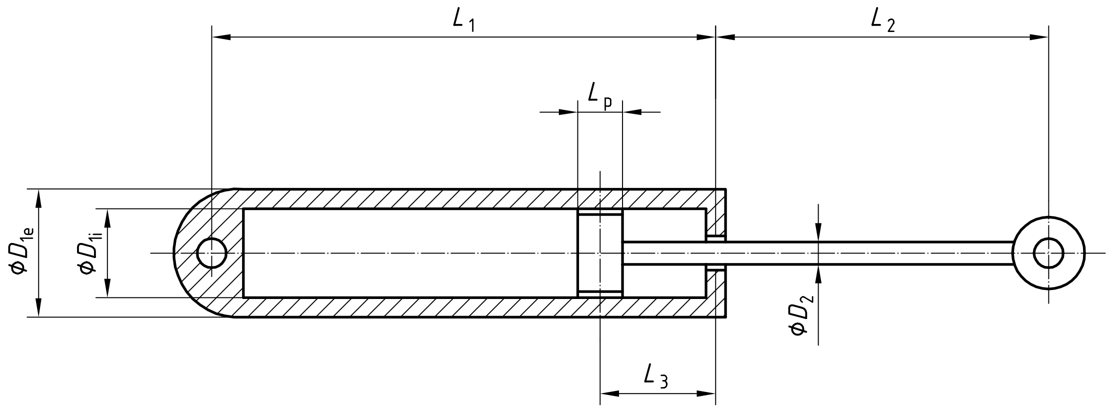
g) is easy to transcribe under the form of a simple computer program.

The results given by this method have been compared favourably to those given by several methods already used in the industry for fluid power cylinders in the range 25 mm to 200 mm with 12 mm to 140 mm piston rods. Accordingly, larger- or smaller-sized cylinder designs should be approached with caution when using this method.

NOTE This method is based mainly on original work by Fred Hoblit (Critical buckling load for hydraulic actuating cylinders, *Product Engineering*, July 1950).

2 Symbols and units

See Figures 1 and 2 and Table 1.



$$L_3 = \frac{L_p + \left(\frac{D_{1e} - D_{1i}}{2}\right)}{2}$$

Figure 1 — Cylinder

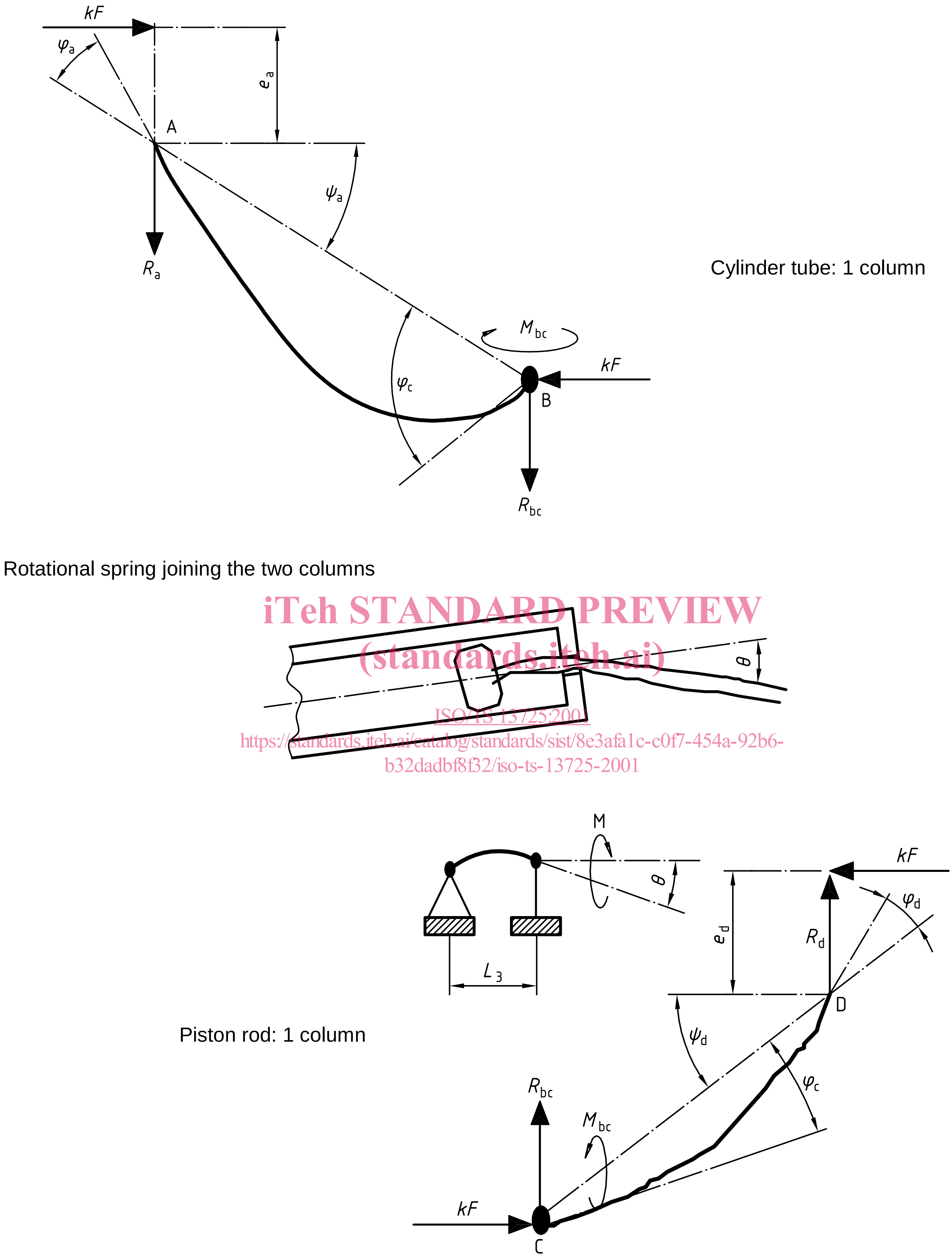


Figure 2 — Model of the hydraulic cylinder

Table 1 — Symbols and units

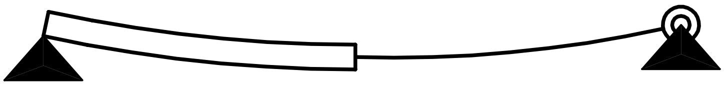
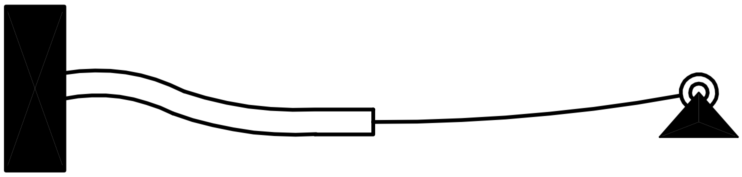
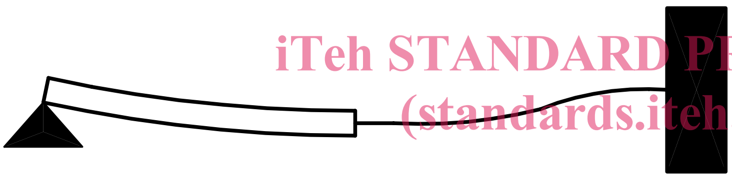
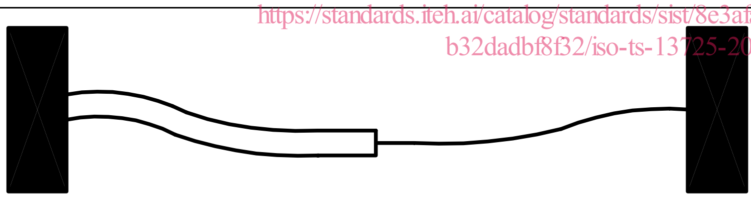
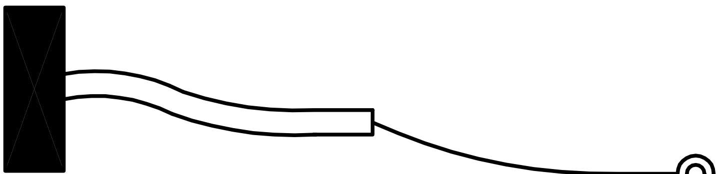
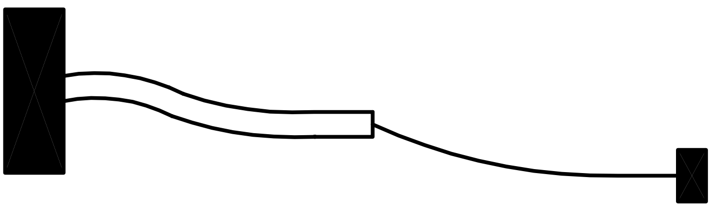
Symbol	Meaning	Unit
C	Stiffness of a spring	N/mm
D	Diameter	mm
D_{1e}	Outside diameter of the cylinder tube	mm
D_{1i}	Inside diameter of the cylinder tube	mm
D_2	Outside diameter of the piston rod	mm
e_a e_d	Distance. The loading of an eccentrically loaded column is equivalent to a concentric axial force F and end moment $M = Fe$	mm
E_1	Modulus of elasticity of cylinder tub material	N/mm^2
E_2	Modulus of elasticity of piston rod material	N/mm^2
f	Deflection of a slender bar	mm
F	Axial force	N
F_{euler}	Euler buckling load	N
I	Moment of inertia	mm^4
I_1	Moment of inertia of the cylinder tube	mm^4
I_2	Moment of inertia of the piston rod	mm^4
k	Factor of safety	
L_1	Cylinder tube length	mm
L_2	Piston rod length	mm
L_3	Length of the portion of rod situated inside the cylinder tube Distance between centreline of piston and piston rod bearing	mm
L_p	Piston length	mm
M	Moment	N/mm
M_a	Fixed-end moment at the beginning of the cylinder tube of a fixed hydraulic cylinder	N/mm
M_{bc}	Moment at junction of cylinder tube and piston rod	N/mm
M_d	Fixed-end moment at the end of the piston rod of a fixed hydraulic cylinder	N/mm
M_{max}	Maximal moment in the piston rod	N/mm
q_1	$\sqrt{\frac{k \times F}{E_1 \times I_1}}$	
q_2	$\sqrt{\frac{k \times F}{E_2 \times I_2}}$	
r	Radius of piston rod	mm
R_a	Reaction at the beginning of the cylinder tube	N
R_d	Reaction at the end of the piston rod	N

Symbol	Meaning	Unit
R_{bc}	Reaction between cylinder tube and piston rod	N
X	Distance from the end of a bar	mm
Y	Deflection of a slender bar at distance X	mm
γ ; g	Acceleration to take into account inertial forces	mm/s^2
Δ	Distance	mm
ε	Small value	
θ	Crookedness angle between the deflection curve of the cylinder tube and the deflection curve of the piston rod	rad
λ	Slenderness ratio: ratio of the column length to the radius of gyration	
ρ_1	Weight per unit volume of cylinder tube material	kg/mm^3
ρ_2	Weight per unit volume of piston rod material	kg/mm^3
σ	Stress	N/mm^2
σ_e	Yield point of a material	N/mm^2
σ_{euler}	Stress at the Euler buckling load	N/mm^2
σ_{max}	Maximum compressive stress	N/mm^2
σ_s	Ultimate strength of a material	N/mm^2
φ_a	Angle of the deflection curve at the beginning of the cylinder tube	rad
φ_b	Angle of the deflection curve at the end of the cylinder tube	rad
φ_c	Angle of the deflection curve at the beginning of the piston rod	rad
φ_d	Angle of the deflection curve at the end of the piston rod	rad
ψ_a	Angle at the beginning of the cylinder tube	rad
ψ_b	Angle at the end of the piston rod	rad

3 Method to be used

See Table 2.

Tableau 2 — Method to be used

Mounting case	Method
	Method for pin-mounted hydraulic cylinders. See chapter 4.
	Method for hydraulic cylinders fixed at the beginning of the cylinder tube and pin-mounted at the end of the piston rod See chapter 5.
	Method for hydraulic cylinders pin mounted at the beginning of the cylinder tube and fixed at the end of the piston rod. See chapter 6.
	Method for hydraulic cylinders fixed at their two ends. See chapter 7.
	Method for hydraulic cylinders fixed at the beginning of the cylinder tube and free at the end of the piston rod. See chapter 8.
	Method for hydraulic cylinders fixed at their two ends with a free move allowed at the end of the piston rod. See chapter 9.

4 Method for pin-mounted hydraulic cylinders

k = [see clause 1, c)].

$$q_1^2 = \frac{kF}{E_1 I_1} \qquad q_2^2 = \frac{kF}{E_2 I_2}$$

$s_1 = \sin(q_1 L_1)$ $\quad C_1 = \cos(q_1 L_1)$ $\quad s_2 = \sin(q_2 L_2)$ $\quad C_2 = \cos(q_2 L_2)$

Step 1

Find the critical buckling load ("force_det") in solving the following equation by trial and error:

$$kFL_3 s_1 s_2 - 3E_2 I_2 q_1 C_1 s_2 - 3E_2 I_2 q_2 C_2 s_1 = 0$$

Step 2

Choose force_a = force_det*epsilon, force_b = force_det*(1 – epsilon)

Calculate the greatest stress σ_a in the piston rod when the hydraulic cylinder is axially loaded by force_a (see computation procedure hereafter).

Calculate the value f_a = $\sigma_a - \sigma_e$ where σ_e is the yield point of piston rod material.

Calculate the greatest stress σ_b in the piston rod when the hydraulic cylinder is axially loaded by force_b.

Calculate the value f_b = $\sigma_b - \sigma_e$

If the value f_a is greater than 0, the greatest allowable compressive load is 0.

If the value f_b is smaller than 0, the greatest allowable compressive load is "force_det",

otherwise, choose force_c = force_a

until the interval (force_d, force_c) is small enough.

Write force_d = force_c

Calculate force_c

force_c = force_a – (force_b – force_a) * f_a / (f_a – f_b)

Calculate the greatest stress σ_c in the piston rod when the hydraulic cylinder is axially loaded by force_c.

Calculate value f_c = $\sigma_c - \sigma_e$

If the value (f_a times f_c) is greater than zero,

write force_a = force_c and f_a = f_c

Then, write force_b = force_c and f_b = f_c

The greatest allowable compressive load is "force_c".