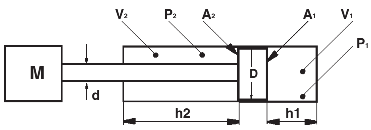
Sizing criteria for cylinders and servocylinders

1 INTRODUCTION

The choice of the hydraulic cylinder is based upon the system working conditions. The following sections show how to choose the suitable hydraulic cylinder to ensure top performances and to avoid mechanical damages.
When high acceleration and/or short cycle times are requested, an analysis performed by the Atos technical office is strongly recommended.

2 SYMBOLS, DIAGRAMS AND BASIC FORMULAE

Single rod cylinders



Pushing area

$$A_1 = \frac{\pi \cdot D^2}{4 \cdot 100} \ [cm^2]$$

Cylinder speed during rod extension

$$V_1 = \frac{10 \cdot Q}{A_1 \cdot 60} \left[\frac{m}{sec}\right]$$

Force applied during rod extension

$$F_p = (p_1 \cdot A_1 - p_2 \cdot A_2) \cdot 10 \quad [N]$$

Pulling area

$$A_2 = \frac{\pi \cdot (D^2 - d^2)}{4 \cdot 100} \ [cm^2]$$

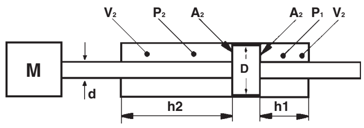
Cylinder speed during rod retraction

$$V_2 = \frac{10 \cdot Q}{A_2 \cdot 60} \left[\frac{m}{sec}\right]$$

Force applied during rod retraction

$$F_p = (p_2 \cdot A_2 - p_1 \cdot A_1) \cdot 10 \quad [N]$$

Double rod cylinders



Pushing and pulling area

$$A_2 = \frac{\pi \cdot (D^2 - d^2)}{4 \cdot 100} \ [cm^2]$$

Cylinder speed during rod extension/retraction

$$V = \frac{10 \cdot Q}{A_2 \cdot 60} \left[\frac{m}{sec}\right]$$

Force applied during rod extension/retraction

$$F_p = (p_2 - p_1) A_2 \cdot 10 \quad [N]$$

Quantity	Unit	Symbol
Force	N	F
Pressure	bar	p
Section	cm^2	A
Bore size	mm	D
Rod diameter	mm	d
Cylinder stroke	mm	h
Flow rate	l/min	Q
Speed	m/s	V
Acceleration	m/s^2	a
Load mass	kg	M

The hydraulic force F_p has to be upper than the algebraic sum of all the forces acting on the cylinder to ensure the performances requested:

$$F_p = F_i + F_f + P$$

$F_i = M \cdot a$ = Inertial forces
F_f = Friction forces
P = Weight (only for vertical loads)

The above formula can be used for the calculation of necessary hydraulic force requested by the particular application.

3 SIZING

The table below reports the push/pull sections and forces for three different working pressures.
Once the push/pull forces are known, the size of the hydraulic cylinder can be choosen from the table below. The values have been determined using the formulae in section 2.

PULL FORCE [kN]

Bore [mm]		25		32		40			50			63			80			100		
Rod [mm]		12	18	14	22	18	22	28	22	28	36	28	36	45	36	45	56	45	56	70
Pull section [cm²]		3,8	2,4	6,5	4,2	10,0	8,8	6,4	15,8	13,5	9,5	25,0	21,0	15,3	40,1	34,4	25,6	62,6	53,9	40,1
Pull force [kN]	p=100 bar	3,8	2,4	6,5	4,2	10,0	8,8	6,4	15,8	13,5	9,5	25,0	21,0	15,3	40,1	34,4	25,6	62,6	53,9	40,1
	p=160 bar	6,0	3,8	10,4	6,8	16,0	14,0	10,3	25,3	21,6	15,1	40,0	33,6	24,4	64,1	55,0	41,0	100,2	86,3	64,1
	p=250 bar	9,4	5,9	16,3	10,6	25,1	21,9	16	39,6	33,7	23,6	62,5	52,5	38,2	100,2	85,9	64,1	156,6	134,8	100,1

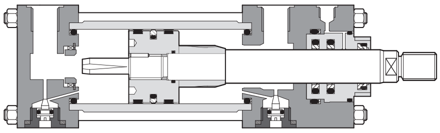
Bore [mm]		125			140	160			180	200			250		320		400	
Rod [mm]		56	70	90	90	70	90	110	110	90	110	140	140	180	180	220	220	280
Pull section [cm²]		98,1	84,2	59,1	90,3	162,6	137,4	106,0	159,4	250,5	219,1	160,2	336,9	236,4	549,8	424,1	876,5	640,9
Pull force [kN]	p=100 bar	98,1	84,2	59,1	90,3	162,6	137,4	106,0	159,4	250,5	219,1	160,2	336,9	236,4	549,8	424,1	876,5	640,9
	p=160 bar	156,9	134,8	94,6	144,5	260,1	219,9	169,6	255,1	400,9	350,6	256,4	539,1	378,2	879,6	678,6	1402,4	1025,4
	p=250 bar	245,2	210,6	147,8	225,8	406,4	343,6	265,1	398,6	626,4	547,8	400,6	842,3	591,0	1374,4	1060,3	2191,3	1602,2

PUSH FORCE [kN]

Bore [mm]		25	32	40	50	63	80	100	125	140	160	180	200	250	320	400
Push section [cm²]		4,9	8,0	12,6	19,6	31,2	50,3	78,5	122,7	153,9	201,1	254,5	314,2	490,9	804,2	1256,6
Push force [kN]	p=100 bar	4,9	8,0	12,6	19,6	31,2	50,3	78,5	122,7	153,9	201,1	254,5	314,2	490,9	804,2	1256,6
	p=160 bar	7,9	12,9	20,1	31,4	49,9	80,4	125,7	196,3	246,3	321,7	407,2	502,7	785,4	1286,8	2010,6
	p=250 bar	12,3	20,1	31,4	49,1	77,9	125,7	196,3	306,8	384,8	502,7	636,2	785,4	1227,2	2010,6	3141,6

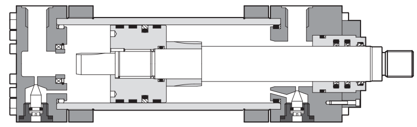
4 CHOICE OF THE CYLINDER SERIES

SERIES CK/CH - tab. B137 - B140 to ISO 6020-2



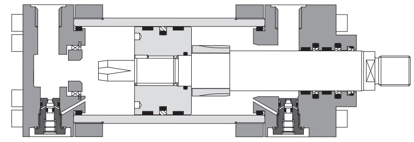
- Nominal pressure **16** MPa (160 bar) - max. **25** MPa (250 bar)
- Bore sizes from **25** to **200** mm
- Rod diameters from **12** to **140** mm

SERIES CH BIG BORE SIZE - tab. B160 to ISO 6020-3



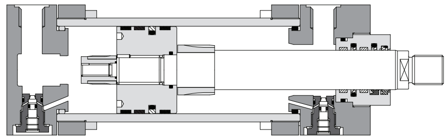
- Nominal pressure **16** MPa (160 bar) - max. **25** MPa (250 bar)
- Bore sizes from **250** to **400** mm
- Rod diameters from **140** to **220** mm

SERIES CN - tab. B180 to ISO 6020-1



- Nominal pressure **16** MPa (160 bar) - max. **25** MPa (250 bar)
- Bore sizes from **50** to **200** mm
- Rod diameters from **28** to **140** mm

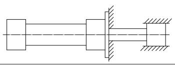
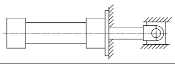
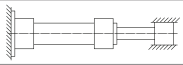
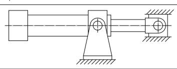
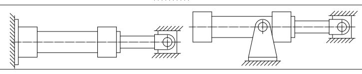
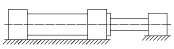
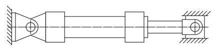
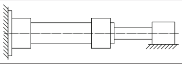
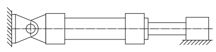
SERIES CC - tab. B241 to ISO 6022



- Nominal pressure **25** MPa (250 bar) - max. **32** MPa (320 bar)
- Bore sizes from **50** to **320** mm
- Rod diameters from **36** to **220** mm

5 CHECK TO THE BUCKLING LOAD

5.1 Calculation of the ideal lenght

Style	Rod end connection	Type of mounting	Fc
A, E, K, N, T, W, Y, Z	Fixed and rigidly guided		0.5
A, E, K, N, T, W, Y, Z	Pivoted and rigidly guided		0.7
B, P, V	Fixed and rigidly guided		1.0
G	Pivoted and rigidly guided		1.0
B, P, V, L	Pivoted and rigidly guided		1.5
A, E, K, N, T, W, Y, Z	Supported but not rigidly guided		2.0
C, D, H, S	Pivoted and rigidly guided		2.0
B, P, V	Supported but not rigidly guided		4.0
C, D, H, S	Supported but not rigidly guided		4.0

For cylinders working with push loads a buckling load's checking has to be considered before choosing the rod size. This check is performed considering the fully extended cylinder as a bar having the same diameter of the cylinder rod (safety criteria).

See the following indications:

1. Determine the stroke factor "Fc" depending to the mounting style and to the rod end connection, see table at side

2. Calculate the "ideal lenght" from the equation:

ideal length = Fc x stroke

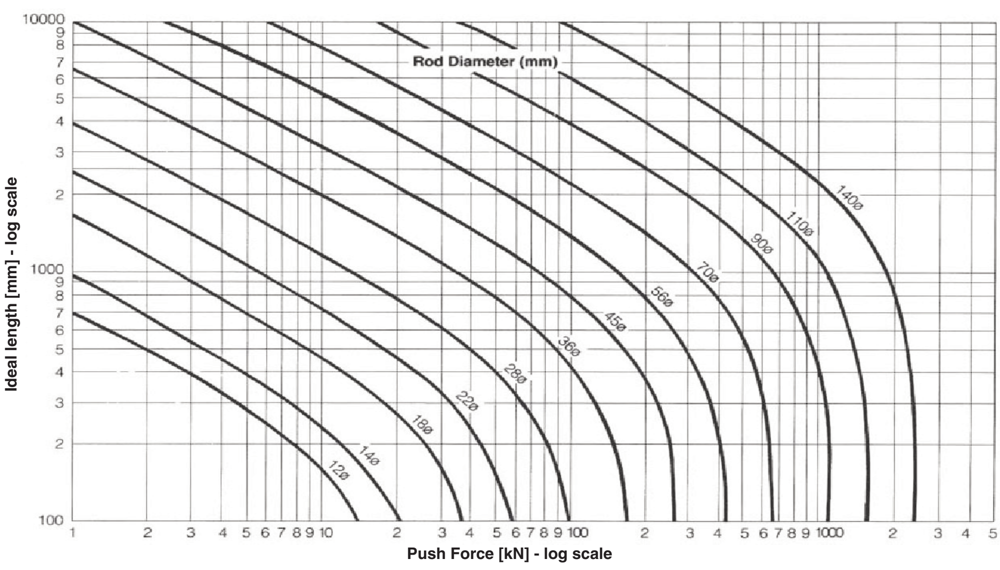
If a spacer has been selected, the spacer's length must be added to the stroke

3. Calculate the push load as indicated in section 3 or using the formulae indicated in section 2

4. Obtain the point of intersection between the push force and the ideal length using the rod selection chart 5.2

5. The correct rod diameter is readen from the curved line above the point of intersection: if the rod diameter choosen is inferior, another one has to be selected

5.2 Rod selection chart



6 CHECK TO THE HYDRAULIC CUSHIONING

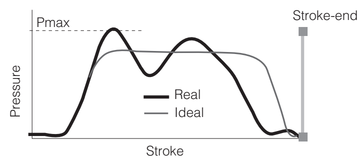
6.1 Introduction

Hydraulic cushionings are a kind of "dumpers" designed to dissipate the energy of a mass connected to the rod and directed towards the cylinder stroke-ends, reducing its velocity before the mechanical contact. This explains why cushionings are recommended in case of rod speeds higher than 0,05 m/s and if is not used any external softening system. Stroke-end cushionings greatly reduce the mechanical shocks, increasing the average life of the cylinder and of the entire system.
The hydraulic cushioning acts along a variable length, depending to the cylinder bore, by isolating the oil volume contained inside, identified as "Cushioning chamber". The energy dissipation in the cylinder/mass system is obtained by causing the outflow of the oil volume of the cylinder chamber by means of calibrated orifices.

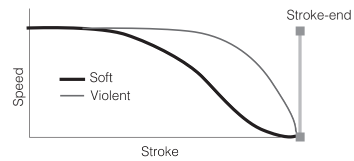
6.2 Functioning features

Cushioning proves to be effective as much as the pressure inside the cushioning chamber gets close to the ideal behaviour described in the diagram at side.
The diagram at side compares the ideal behaviour with Atos typical real pressure profile, achieved by optimizing the design of the profile of the restricted orifices.
In this way high performances have been obtained in terms of dissipated energy with great repeatability even with fluid viscosity variations due to temperature or to different types of fluids.
Another significant data to take into account is the maximum deceleration value produced by the cushioning (for the same quantity of energy dissipated): this can generate excessive inertial forces, harmful for the cylinder.
Atos cushionings profile is designed to exploit at the best the whole cushioning stroke and to perform a "soft" cushioning (see figure at side), where the maximum deceleration is limited and kept constant for its full length. A "soft" cushioning reduces mechanical shocks which may damage mechanical parts inside or outside the cylinder such as eyes, rod/piston, attachments, etc.
The maximum pressure rate achieved in the cylinder chamber corresponds to the maximum cylinder deceleration and it directly depends to the speed at which the cylinder starts the cushioning phase: such pressure must never overcome the maximum value indicated in tab. 6.5.

Pressure in the cushioning chamber



Speed during cushioning



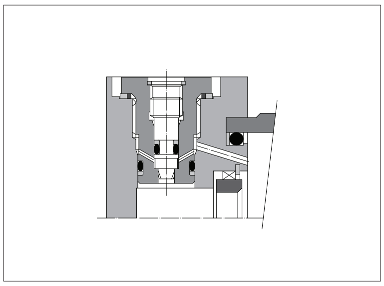
6.3 Application features

The following guidelines refer to CK and CH cylinders: for cylinders CN, CC and CH big bore size, contact our technical office.
In order to allow the use of cushioning in various applications, three different cushioning versions have been developed:

- Slow version, provided with adjustment, for speed V ≤ 0,5 • Vmax
- Fast version, without adjustment, for speed V > 0,5 • Vmax
- Fast version, provided with adjustment, for speed V > 0,5 • Vmax

The maximum permitted speed value Vmax depends to the cylinder size as reported in tab. 6.5.
When fast or slow adjustable versions are selected, the cylinder is provided with a needle valve, represented in the figure at side, to optimize the cushioning performances.
Adjustable versions allow to adapt with accuracy the cushioning effects and the relevant times to the specific application requirements, thus they are recommended for cylinders with high speeds and low inertial loads. The opening of the adjustment screw decreases the cushioning effect, with a consequent decreasing of the cushioning time.

Adjustment screw



6.4 Calculation procedures

Once the cushioning is selected according to the cylinder speed, it will be necessary to check its compatibility with the specific application and, particularly, the total energy to dissipate. It is necessary to calculate the total energy that has to be dissipated **E_{tot}** as follows:

$$E_{tot} = E_c + E_i + E_p$$

- **Kinetic energy E_c**, due to the mass speed

$E_c = 1/2 \cdot M \cdot V^2$ [Joule]

- **Hydraulic energy E_i**, given by the pressure supplied to the cylinder

For rear cushioning

$E_i = K \cdot Lf \cdot p \cdot A_1$ [Joule]

For front cushioning

$E_i = K \cdot Lf \cdot p \cdot A_2$ [Joule]

- **Potential energy E_p**, due to the gravity and related to the cylinder inclination

For rear or front cushioning with the inclination angles indicated in the figures at side :

$$E_p = + K \cdot Lf \cdot \frac{M \cdot g \cdot sen\,\alpha}{10} \quad [Joule]$$

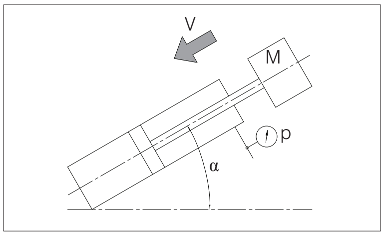
For rear or front cushioning with the inclination angles opposite to those indicated in the figures at side:

$$E_p = - K \cdot Lf \cdot \frac{M \cdot g \cdot sen\,\alpha}{10} \quad [Joule]$$

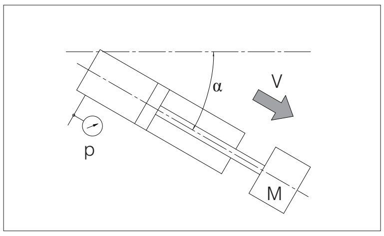
Where:

M = Mass [kg]
V = Rod speed [m/s]
K = Corrective coefficient (see tab. 6.5)
Lf = Cushioning length [mm] (see tab. 6.5)
p = Working pressure [bar]
A_1 = Pull section [cm^2]
A_2 = Push section [cm^2]
g = Gravity acceleration (9,81 m/s^2)
α = Inclination angle [degree]

Rear cushioning



Front cushioning



E_{tot} has to be compared to **E_{max}** values indicated in tab. 6.5 and the following formula has to be verified:

$$E_{tot} \leq E_{max}$$

Notes:
- If slow cushioning is selected for high speed, the verification related to the above mentioned criteria will have to be done by reducing by 30% the **E_{max}** value of tab. 6.5 (example: for the rear cushioning on a CK-50/28, use **E_{max}** = 0,7 • 400 = 280 Joule)
- For the front cushioning, if the supply pressure p is higher than the **p_{max}** shown in tab. 6.5, a deep analysis of the application is required, contact our technical office

6.5 Calculation parameters

ø Bore [mm]	V_{max} [m/s]	ø Rod [mm]	A1 Pull sect. [cm^2]	A2 Push sect. [cm^2]	p_{max} * [bar]	Front cushioning K	Front cushioning Lf [mm]	Front cushioning E_{max} [Joule]	Front cushioning Section [cm^2]	Rear cushioning K	Rear cushioning Lf [mm]	Rear cushioning E_{max} [Joule]	Rear cushioning Section [cm^2]
25	1	12	3,8	4,9	180	0,0045	21	80	3,6	0,0035	12,5	80	4,5
		18	2,4		107	0,0057	17	60	2,1				
32	1	14	6,5	8,0	187	0,0033	23	140	6,0	0,0049	14,5	140	7,4
		22	4,2		122	0,0045	17	100	3,9				
40	1	18	10	12,6	173	0,0036	26	250	8,7	0,0027	27	300	11,9
		22	8,8		110	0,0044	25	150	5,5				
		28	6,4										
50	1	22	15,8	19,6	150	0,0035	28	350	13,5	0,0017	28	400	18,5
		28	13,5		106	0,0048	27	250	8,3				
		36	9,6										
63	0,8	28	25	31,2	160	0,0016	28	500	22,1	0,0016	27	600	29,1
		36	21		110	0,0040	27	350	13,8				
		45	15,3										
80	0,8	36	40,1	50,3	181	**	27	**	36,4	**	29	**	46,4
		45	34,4		118		29		23,8				
		56	25,6										
100	0,6	45	62,6	78,5	169	**	35	**	53	**	29	**	73,2
		56	53,9		120		27		37,8				
		70	40,1										
125	0,6	56	98,1	122,7	167	**	28	**	82	**	29,9	**	114
		70	84,2		105		25		51,8				
		90	59,1										
160	0,5	70	162,6	201,1	167	**	34	**	134,6	**	29,5	**	189
		90	137,4		127		31		102,5				
		110	106										
200	0,5	90	250,5	314,2	191	**	46	**	240,3	**	29,5	**	294
		110	219,2		168		33		215,6		30		
		140	160,2		120		46		151,3		29,5		

Notes:
(*) $\mathbf{p_{max}}$ = cylinder maximum working pressure
(**) For the max dissibable energy and bores greater than 200, contact our technical office

7 DYNAMIC LIMITS IN THE APPLICATION OF HYDRAULIC CYLINDERS

The calculation of pulsing value ω_o of the cylinder-mass system allows to define the minimum acceleration/deceleration time, the max speed and the min. acceleration/deceleration space to not affect the functional stability of the system.

7.1 System pulsation value ω_o

$$\omega_o = \sqrt{\frac{40 \cdot E \cdot A_1}{c \cdot M}} \cdot \frac{1 + \sqrt{\alpha}}{2} \quad \left[\frac{rad}{s}\right]$$

where:
E = oil modulus of elasticity ($1.4 \cdot 10^7$ kg/cm·s^2)
c = stroke [mm]
M = mass [kg]
A_1 = piston section [cm^2]
α = A_2/A_1 pushing / pulling area ratio

7.2 Minimum acceleration time

$$t_{min} = \frac{35}{\omega_o} \quad [s]$$

7.3 Maximum speed

$$V_{max} = \frac{S_{tot}}{t_{tot} - t_{min}} \quad [mm/s]$$

where: S_{tot} = total space to run [mm]
t_{tot} = total time at disposal [s]

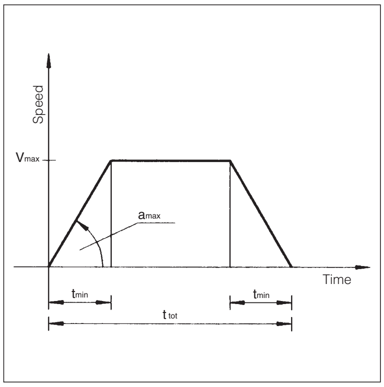
The formula is valid considering a constant acceleration value during t_{min}

Check that the maximum speed is according to the selected seals, see the table of the cylinder series choosen.

7.4 Minimum acceleration/deceleration space

$$S_{min} = \frac{V_{max} \cdot t_{min}}{2} \quad [mm]$$

Positioning cycle



The ω_o, t_{min}, V_{max} and S_{min} values are calculated in conservative way.
Check that the value S_{min} as above calculated is not higher than the length Lf indicated in tab. 6.5 for the selected cylinder bore.