Atos spa
21018 Sesto Calende, Italy - Fax 0331 920005

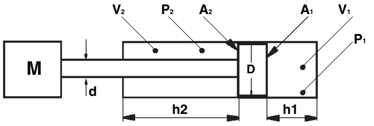
Criteria for sizing of cylinders and electrohydraulic servocylinders

1 STATIC AND DYNAMIC CONTROLS

For all working conditions, it is necessary to check the static and dynamic characteristics described in the following.
When determining the forces acting on the system, must be considered the forces of inertia, the external friction forces and the counterpressures generated by effect of cushioning and restrictor valves installed in the hydraulic circuit.
For an overall check of the system, an analysis performed by the Atos technical office is recommended, especially where high acceleration and/or short cycle times are requested.

2 SYMBOLS, DIAGRAMS AND BASIC FORMULA

Single rod cylinders



Cylinder speed during rod extension

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

Cylinder speed during rod retraction

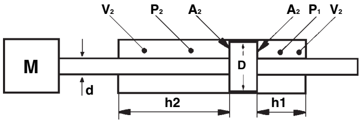
$$V_2 = \frac{10 \cdot Q}{A_2 \cdot 60} \left[\frac{m}{sec}\right]$$

Force applied during rod extension
$F = (p_1 \cdot A_1 - p_2 \cdot A_2) \cdot 10$ [N]

Force applied during rod retraction
$F = (p_2 \cdot A_2 - p_1 \cdot A_1) \cdot 10$ [N]

where: $A_1 = \frac{\pi \cdot D^2}{4 \cdot 100}$ [cm²] $A_2 = \frac{\pi \cdot (D^2 - d^2)}{4 \cdot 100}$ [cm²]

Double rod cylinders



Cylinder speed during rod

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

Force applied
$F = (p_2 - p_2) A_2 \cdot 10$ [N]

Quantity	Unit	Symbol
Total force (1)	N	F
Pressure	bar	p
Section	cm²	A
Bore diameter	mm	D
Rod diameter	mm	d
Cylinder stroke	mm	h
Flow rate	l/min	Q
Speed	m/sec	V
Acceleration	m/sec²	a
Load mass	Kg	M

(1) The total force is the algebraic sum of all the forces acting on the cylinder:
Forces of inertia = Fi = M•a
Working forces = Fl
Friction forces = Fa
Weight (only for vertical loads) = P

3 SIZING

The table below reports the thrust/retracting sections of the different size combinations rod/piston.

The rod/piston size, based on the system parameters (force, speed, flow) is determined with the formulae reported in section 2 and with the figures obtained from this table.
Calculation can be checked also graphically with the nomographs of table P003.
The rod dimension must be checked to the buckling load, according to what reported in section 4.

Piston [mm]	**25**		**32**		**40**			**50**			**63**			**80**			**100**		
Extention section A1-[cm²]	4,9		8,0		12,6			19,6			31,2			50,3			78,5		
Rod [mm]	**12**	**18**	**14**	**22**	**18**	**22**	**28**	**22**	**28**	**36**	**28**	**36**	**45**	**36**	**45**	**56**	**45**	**56**	**70**
Retraction section A2-[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

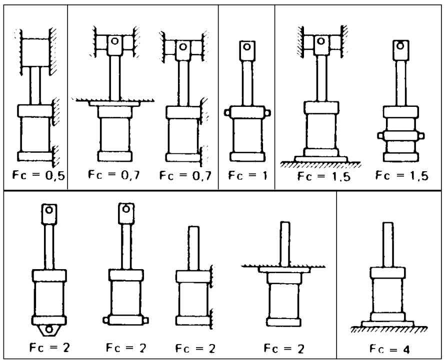
Piston [mm]	**125**			**140**		**160**			**180**		**200**			**250**		**320**		**400**	
Extention section A1-[cm²]	122,7			153,9		201,1			254,5		314,2			490,9		804,2		1256,6	
Rod [mm]	**56**	**70**	**90**	**90**		**70**	**90**	**110**	**110**		**90**	**110**	**140**	**140**	**180**	**180**	**220**	**220**	**280**
Retraction section A2-[cm²]	98,1	84,2	59,1	90,3		162,6	137,4	106,0	159,4		250,0	219,2	160,2	336,9	236,4	549,8	424,1	876,5	640,9

4 CHECK TO THE BUCKLING LOAD

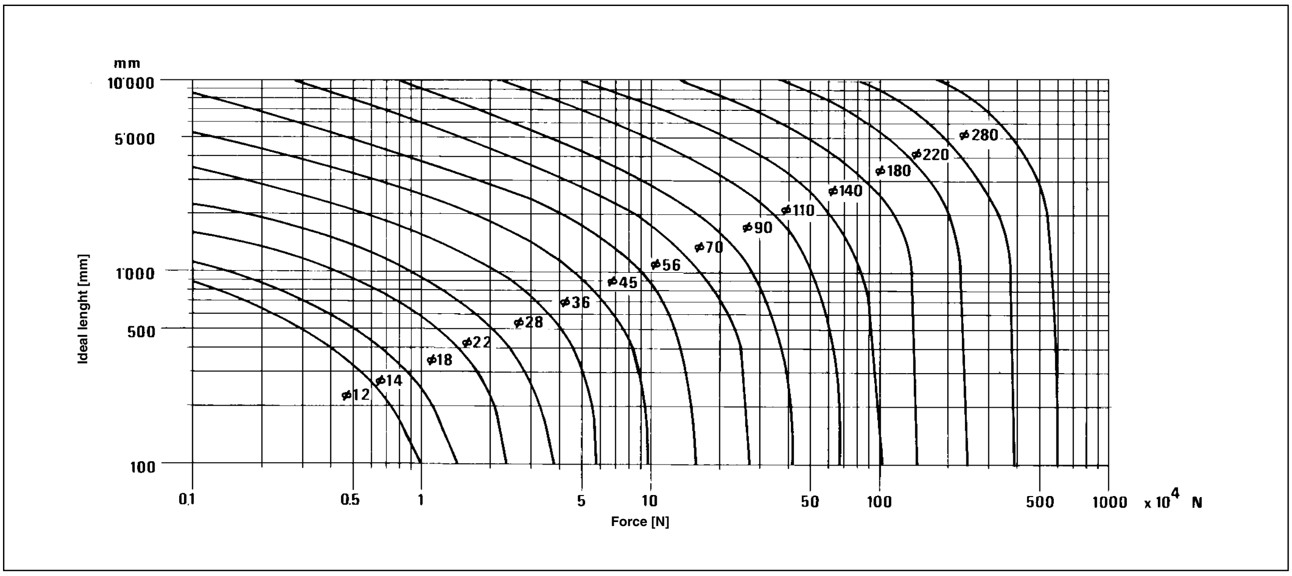
This check is performed considering the fully extended cylinder as a bar having the same diameter of the cylinder rod (safety criteria):

- Depending on the data for the mechanical connection of the cylinder to the structure, obtain the “**Fc** stroke factor” from table 4.1:
- Calcolate the “ideal length **Li**” multypling the factor Fc by the cylinder stroke L [mm]: **Li = L x Fc**
- Obtain on diagram 4.2 the point of intersection between the Li ideal length value and the max. force value (N) of the cylinder.
- The rod satisfying the verification at max. load conditions, is the one corresponding to the curve immediately above the intersection point found on diagram 4.2.

4.1 Fc stroke factor



4.2 Checking diagam



5 CHECK OF HYDRAULIC CUSHIONING

Introduction

Hydraulic cushions of cylinders are a kind of “dumpers” designed to dissipate the energy of a mass connected to the cylinder the rod and directed towards the cylinder stroke-end, reducing its velocity before the mechanical contact. This explains why cushions are advisable in case of rod translation speeds higher than 50 mm/sec, if no softening systems, external to the cylinder are used. Stroke-end cushionings greatly reduce mechanical shocks, increasing the average life of the cylinder and of the entire system.

The hydraulic cushion acts along a variable length, depending on cylinder bore, by isolating the oil volume contained in this section, identified as “Cushioning chamber”.

The energy dissipation in the cylinder/mass system (cushioning) is obtained by causing the downflow of the oil volume inside the cylinder chamber by means of calibrated orifices.

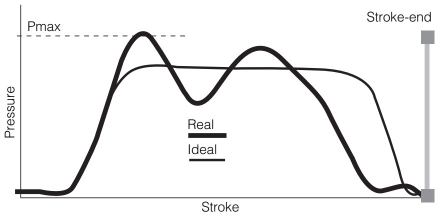
Functioning features

Cushioning proves to be most effective as the pressure inside the cushioning chamber gets close to the ideal behaviour described in the aside diagram.

Fig. 5.1 compares the ideal behaviour with Atos typical real pressure profile, achieved by optimizing the profile of the restricted orifices of the cushioning.

In this way high performances have been obtained in terms of dissipable energy and with great repeatability even with fluid viscosity variations due to temperature, or due to different types of fluids.

5.1 Pressure in the cushioning chamber



Another significant data to take into account is the maximum deceleration value produced by the cushioning (at the same quantity of energy dissipated), which can generate excessive inertia forces, which can be harmful to the cylinder.

Atos cushions profile is designed to exploit at the best the whole cushioning stroke and to perform a “soft” cushioning, where the maximum deceleration is limited and kept constant for its full length.

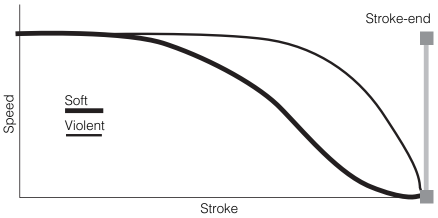
A “soft” cushioning reduces mechanical shocks which may damage mechanical parts inside or outside the cylinder, such as eyes, rod/piston, attachments, etc.

Fig. 5.2 compares the Atos “soft” cushioning with a typical “violent” cushioning.

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 permitted.

5.2 Speed during cushioning



Application features

The guideline following reported referes to CK cylinders.
For cylinders CN, CC, CH big bore size, consult our technical office.

In order to allow the use of cushions in the various applications three different cushioning versions have been developed:

- Slow version, provided with adjustment, for speed $V \leq 0,5 \bullet Vmax$;
- Fast version, without adjustment, for speed $V > 0,5 \bullet Vmax$;
- Fast version, provided with adjustment, for speed $V > 0,5 \bullet Vmax$;

The maximum permitted speed value Vmax depends to the cylinder bore and it is reported in tab. 5.5.

Cushions in “slow” version are always provided with adjustment, since used in slow speed conditions, this may result in excessive cushioning times increasing the machine cycle time. In fact it may happens that after a certain cushioning stroke, the cylinder speed is reduced at very low values and the time to approach the mechanical stroke-end could be excessive; the opening of the adjustment decreases the cushioning time, but it increases the speed in the remaining stroke of the cylinder before the stroke-end is reached, with a consequent decreasing of the cushioning effect.
On the opposit, the “fast” versions, suitable for high speeds, is less “flow restricted” and therefore has reduced cushioning times. They can be used in slow speeds as wel ($V \leq 0,5 \bullet Vmax$); with the effect of having a very quick cushioning, perceivable only in last few millimetres before the stroke-end.
The “fast” version provided with adjustment allows to adapt with accuracy the cushioning effects and relevant times to the specific application requirements. Thanks to this characteristics it is advisable for cylinders with high speeds and low inertial loads.

Calculation procedures

Once the cushion is selected according to the cylinder translation time, will be necessary to check its compatibility with the specific application and particularly with the total energy to dissipated.

The total energy that the cushion must dissipate is given by the sum of the following three factors:
- Kinetic energy **Ec**, due to the mass speed;
- Hydraulic energy **Ei**, given by the pressure supplied to the cylinder;
- Potential energy **Ep**, due to the gravity and related to the cylinder inclination.

All the above factors are important and must be taken into consideration.

A summarizing scheme of the cylinder/mass system, as the same one reported in fig. 5.3 and 5.4, allows an easy and immediate dimensional check of the cushion. It is necessary to calculate the total energy to be dissipated **Etot** and compare it with the maximum permitted value **Emax** shown in table 5.5, according to the Bore/rod combination.
Parameters to be known are:

- Rod speed **V** [m/s], at which the cylinder begans the cushioning stroke;
- Supply pressure (actual value during cushioning stroke) **P** [bar];
- Inclination angle of the cylinder **α**;
- Mass connected to the rod **M** [Kg].

Proceed as follows:

To calculate the Kinetic Energy

$\mathbf{Ec} = 1/2 \bullet M \bullet V^2$ [Joule]

To calculate the Hydraulic Energy

For the verification of the rear cushion (fig. 5.3)

$Ei = K \bullet Lf \bullet P \bullet S1$ [Joule]

For the verification of the front cushion (fig. 5.4)

$Ei = K \bullet Lf \bullet P \bullet S2$ [Joule]

To calculate the Potential Energy

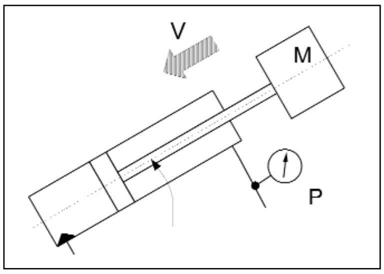
If the mass movement occurs as shown in fig. 5.3 and 5.4

$$Ep = +K \cdot Lf \cdot \left[\frac{M \cdot g \cdot sen(\alpha)}{10}\right] \quad \text{[Joule]}$$

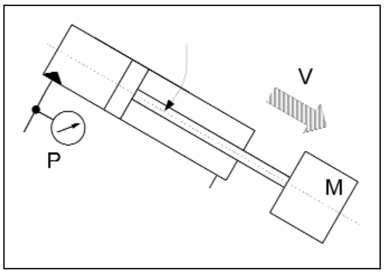
If the mass movement occurs in the opposite direction compared to the ones of fig. 5.3 and 5.4.

$$Ep = -K \cdot Lf \cdot \left[\frac{M \cdot g \cdot sen(\alpha)}{10}\right] \quad \text{[Joule]}$$

5.3 cushioning acting on the Rear Cushion



5.4 cushioning acting on the Front Cushion



K = Corrective coefficient (tab. 5.5)
S1 = Pull section in cm^2
S2 = Push section in cm^2
g = Gravity acceleration (9,81 m/s^2)
Lf = Cushion length in mm (tab. 5.5)

Calculate the total energy to dissipate

Etot = Ec + Ei + Ep [Joule]

Make sure that the obtained **Etot** value is lower or equal to the **Emax** value shown in tab. 5.5.

Notes: If a fast cushioning is selected for a slow moving cylinder, the verification related to the above mentioned criteria will have to be done by reducing by 30% the **Emax** value of tab. 5.5 (example: rear cushioning on a CK-50/28, use an **Emax** = 0,7 • 400 = 280 Joule).

If cushioning acts on the front cushion and the supply pressure P is higher than the **Pmax** shown in tab. 5.5, a deep analysis of the application is required, consult our technical department.

5.5 Calculation parameters

ø Piston [mm]	V_{max} [m/s]	ø Rod [mm]	S1 Pull sect. [cm²]	S2 Push sect. [cm²]	P_{max} [bar]	Front cushion K	Front cushion Lf [mm]	Front cushion E_{max} [Joule]	Front cushion Cushioning Sect. [cm²]	Rear cushion K	Rear cushion Lf [mm]	Rear cushion E_{max} [Joule]	Rear cushion Cushioning Sect. [cm²]
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		

P_{max} = maximum actual pressure allowable during the front cushioning stroke.
* consult our technical office.
For bore greater than Ø200 consult our technical office.

6 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, wich do not affect the functional stability of the system.

System pulsation value ω_o

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

where:
E = oil modulus of elasticity ($1.4 \cdot 10^7$ kg/cm·s²)
c = stroke [mm]
M = mass [kg]
A_1 = piston section [cm²]
α = A_2/A_1 annular/piston cross section ratio

Minimum acceleration time, see fig. 6.1

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

Maximum speed, see fig. 6.1

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

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

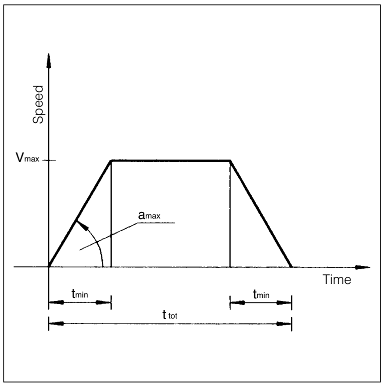
The formula is valid considering a constant acceleration value during t_{min}

Check that the maximum speed is according to the selected seals. See tab. B005.

Minimum acceleration/deceleration space

$$S_{min} = \frac{V_{max} \bullet t_{min}}{2} \text{ [mm]}$$

6.1 Positioning cycle



The ω_o, and t_{min} values and so the 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. 5.5 for the selected cylinder bore.