FLUID POWER

ENGINEER'S DATA BOOK

A PUBLICATION OF:

BFPA

The British Fluid Power Association

FOREWORD

THIS PUBLICATION IS DESIGNED TO BE A QUICK REFERENCE BOOK FOR ALL FLUID POWER SYSTEM DESIGNERS, ENGINEERS AND STUDENTS ASSOCIATED WITH HYDRAULIC OR PNEUMATIC APPLICATIONS. WE GRATEFULLY ACKNOWLEDGE THE CONSIDERABLE HELP AND ADVICE FROM OUR MEMBER COMPANIES IN THE COMPILATION OF THIS DATA BOOK.

Further copies of this data book and the guidelines documents quoted in the text may be obtained from:

THE BRITISH FLUID POWER ASSOCIATION
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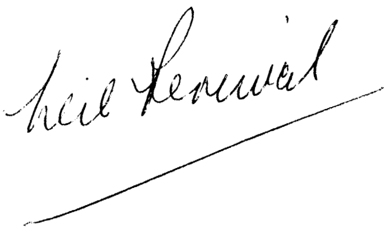
THE BFPA

The **BRITISH FLUID POWER ASSOCIATION** represents over 90% of the manufacturers and suppliers of hydraulic and pneumatic equipment in the United Kingdom. It is the recognised authority for the industry on technical standards and marketing data and is your assurance for customer satisfaction.

For positive commitment to quality and customer care, use a product of a BFPA member company, obtained either from a BFPA member or a member of the British Fluid Power Distributors Association (BFPDA).



Neil Percival

Director (BFPA)

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TERMINOLOGY

The main source of fluid power terms and definitions is the International Standard - ISO 5598 - Fluid Power Systems and Components - Vocabulary, however, new definitions are arising from recent work on E.U. - CEN standards.

The following are just a few of the fluid power terms in every day use for hydraulic and pneumatic applications:-

Fluid power - The means whereby signals and energy can be transmitted, controlled and distributed, using a fluid as the medium.

Hydraulics - Science and technology which deals with the laws governing liquid flow and pressure.

Pneumatics - Science and technology which deals with the use of air or neutral gases as the fluid power medium.

System - Arrangement of interconnected components which transmits and controls fluid power energy.

Machinery - An assembly of linked parts or components, at least one of which moves, with the appropriate actuators, control and power circuits etc., joined together for a specific application.

Component - An individual unit (e.g. actuator, valve, filter) comprising one or more parts, designed to be a functional part of a fluid power component or system.

Actuator - A device which converts energy into force and movement. The movement may be linear (e.g. cylinder), semi-rotary (e.g. torque unit), or rotary (e.g. motor).

Operating conditions - Operating conditions are indicated by the numerical values of the various factors relating to any given, specific application of a unit. These factors may vary during the course of operations.

Working pressure - Pressure at which the apparatus is being operated for a given application.

System pressure - Pressure measured at the inlet to the first valve or at pump outlet (normally the relief valve setting).

Pilot pressure - pressure in a pilot line or circuit.

Hydraulic pumps - Units which transform mechanical energy into hydraulic energy.

Compressors - Devices which cause a gas to flow, against a pressure: they convert mechanical energy into pneumatic fluid power.

Directional control valve - Device connecting or isolating one or more flow paths.

Control mechanisms - The means whereby components change their state. Control mechanisms may be manual, mechanical, pressure or electrical in operation.

Pressure relief valve - Valve which limits maximum pressure by exhausting fluid to tank when the required pressure is exceeded.

Systems of Units and Conversions

Quantity	*SI*		*Imperial*	
MASS	kilogram	kg	pound mass 1lb = 0.4536 kg	lb
FORCE	newton	N	pound force 1lbf = 4.45N	lbf
WORK	joule	J	foot pound force 1ft lbf = 1.356J	ft lbf
POWER	watt	w	foot pound force per second 1ft lbf/sec = 1.356W horse power 1hp = 745.7W	ft lbf/sec hp
VELOCITY	metre per second 1m/s = 3.28 ft/s	m/s	feet per second	ft/s
LENGTH	metre 1m = 39. 37 in micron 1µm = 10^{-6}m	m µm	inch	in
PRESSURE	newton per square metre 1 bar = 10^5 N/m^2 1 atmosphere = 1.013 x 10^5 N/m^2 1Pa = 1N/m^2	N/m^2	pound force per square inch 1lbf/in^2 = 6897 N/m^2	lbf/in^2
DENSITY	kilogram per cubic metre	kg/m^3	pound mass per cubic foot 1lb/ft^3 = 16.02kg/m^3	lb/ft^3
AREA	square metre 1m^2 = 1550 in^2	m^2	square inch 1in^2 = 0.645 x 10^{-3} m^2 1in^2 = 6.45cm^2	in^2
VOLUME	cubic metre 1m^3 = 10^3 litre 1m^3 = 220 gall	m^3	cubic inch 1in^3 = 16.39 x 10^{-6} m^3 gallon 1gall = 277.4in^3 1gall = 0.00454m^3 cubic foot 1ft^3 = 6.23gall	in^3 gall ft^3
FLOW RATE	cubic metres per second 1m^3/s = 13.2 x 10^3 gall/min	m^3/s	cubic inches per minute gallons per minute 1 l/min = 0.22 gall/min 1 l/min = 1.66 x $10^{-5}$$m^3$/s 1$ft^3$/min = 28.32 x 10^{-3} m^3/min	in^3/min gall/min
VISCOSITY	1cSt = $10^{-6}$$m^2$/s			

GENERAL

NATIONAL AND INTERNATIONAL STANDARDS AND CETOP RECOMMENDATIONS

BSI and ISO standards are available for reference in most large reference libraries and are available for purchase from BSI Sales, Customer Services, 389 Chiswick High Road, London W4 4AL Tel: 0181 996 7000, Fax: 0181 996 7001. CETOP (European Oil Hydraulic and Pneumatic Committee) recommendations are available from BFPA.

The following lists of standards and recommendations are selected from the hundreds of fluid power standards which exist, as having the most relevance to design aspects of the fluid power categories in which they are listed.

The designer needs to be aware of CEN standards associated with the Machinery Directive, 89/392/EEC, etc., such as EN292, EN414, EN982 and EN983.

Many of the British Standards are similar or identical to some of the ISO Standards. No equivalence is implied by reading across the tables.

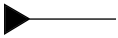
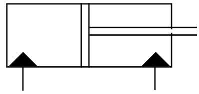
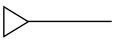
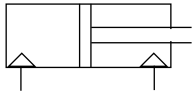
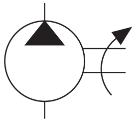
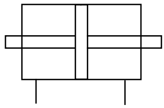
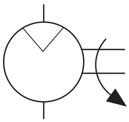
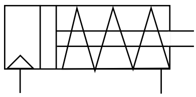
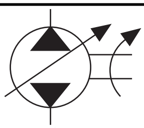
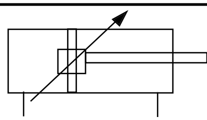
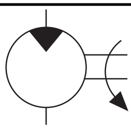
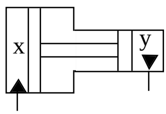
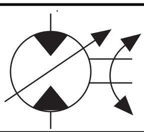
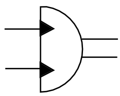
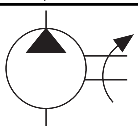
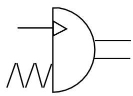
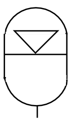
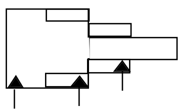
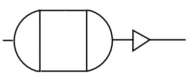
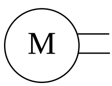
SUBJECT		INTERNATIONAL STANDARDS (ISO)	BRITISH STANDARDS (BS)	CETOP RECOMMENDATIONS
Symbols		1219–1	2917	
Units		31	5775	RP71
Vocabulary		5598		
Hydraulic Pumps and Motors	Mounting Dimensions	3019	6276	
	Parameter Definitions	4391		R8H
Hydraulic Cylinders	Mounting Dimensions	6020 6022 6981 6982 8132 8133	6331	R58H RP73H RP87H RP88H
	Other Parameters	3322 4393 4395 7181 8136 8137 8138	5755	
	Acceptance Tests	10100		RP104H
Pneumatic Cylinders	Mounting Dimensions	6430 6431 6432 8139 8140	4862	
	Other Parameters			RP4P
	Acceptance Tests	10099		RP105P
Hydraulic Valves Mounting Dimensions	Sub-Plate	4401 5781 6263 6264 7790	6494	RP99H RP115H RP121H
	Cartridge	7368	7296	RP96H RP108H

SUBJECT		INTERNATIONAL STANDARDS (ISO)	BRITISH STANDARDS (BS)	CETOP RECOMMENDATIONS
Pneumatic Valves	Mounting Dimensions	5599	7389	RP114P
Seals & Seal Housings	Dimensions	3601-1 3601-4 10766 5597 6194 6195 6547 7425	1806 4518 5106 5751 6241	
Connectors & Port Dimensions	Hydraulic & Pneumatic	7 228 6149 7241-1 8434 1179 9974 11926	21 2779 4368 5200 5327 5380 6537 7198/1 7417	RP63H RP80
Steel Tubes		2604 4200	7416 3602/1	
Nylon Tubing		7628-1	5409/1	
Hydraulic Fluids	Classifications	6743-4 3448	4231 6413/4	RP123H
	Fire Resistant	7745	7287	
	Specifications			R39H RP91H RP97H RP110H
Hydraulic Filters	Designation	7744	6851	RP92H RP98H RT117H RT118H
FRL	Specification	6301		
Contamination Levels		3938 4406	5540/4 5540/5 7265	
Hose & Hose Assemblies	Specifications	1436 3862 3949 4079 6805 7751	3832 4586 4749 4983 6596	R34
	Pneumatic	2398 5774	5118 6066	
Accumulators		5596	7201	RP47H RP62H
Reservoirs			6525	
Electrical Connectors		4400 6952	5630 6361	
Systems	Fluid Power (Hyd. & Pneu.)	1219-2	7388 4575/3	
	Hydraulic	4413	4575/1	
	Pneumatic	4414	4575/2	

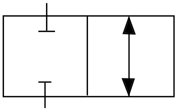
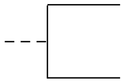
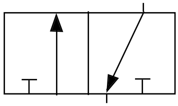
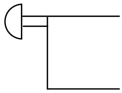
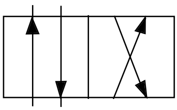
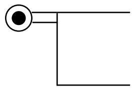
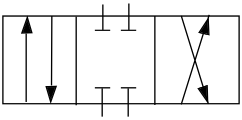
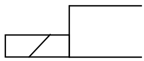
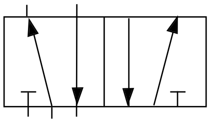
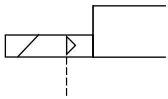
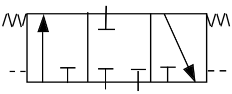
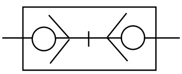
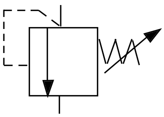
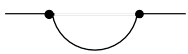
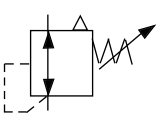
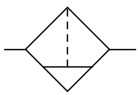
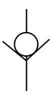
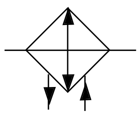
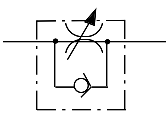
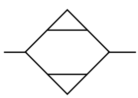
GENERAL

HYDRAULIC AND PNEUMATIC SYMBOLS

ISO 1219-1 covers graphic symbols for both hydraulic and pneumatic equipment. this standard was amended in1991

Symbol	Description	Symbol	Description
	Source of energy -Hydraulic		Hydraulic cylinder -Double-acting
	Source of energy -Pneumatic		Pneumatic cylinder -Double-acting
	Hydraulic pump Fixed displacement One flow direction		Cylinder -Double-acting -Double-ended Piston rod
	Pneumatic motor Fixed displacement One flow direction		Pneumatic cylinder -single-acting -Spring return
	Hydraulic pump Variable displacement Two flow directions		Cylinder -Double-acting Adjustable cushions both ends
	Hydraulic motor Fixed displacement One flow direction		Pressure intensifer -Single fluid -Hydraulic
	Hydraulic motor Variable displacement Two flow directions Two directions of rotation		Semi-rotary actuator -Double-acting -Hydraulic
	Air compressor		Semi-rotary actuator -single-acting -Spring return -Pneumatic
	Accumulator - Gas loaded		Telescopic cylinder -Double-acting -Hydraulic
	Air receiver		Electric motor (From IEC 617)

For circuit diagram layout rules, *see* **ISO 1219-2**
For port identification and operator marking, see **ISO 9461** (Hydraulic) or **CETOP RP68P** or **ISO 5599** (Pneumatic)

Symbol	Description	Symbol	Description
	Directional control 2/2 valve		Valve control mechanism -by pressure
	Directional control 3/2 valve		Valve control mechanism -by push button
	Directional control 4/2 valve		-by roller
	Directional control 4/3 valve -Closed centre		-by solenoid -direct
	Directional control 5/2 valve		-by solenoid -with pressure pilot -pneumatic
	Directional control 3/3 valve -Closed centre -Spring-centred, pilot operated		Quick -release coupling -with non-return valves -connected
	Pressure relief valve -single stage -adjustable pressure		Flexible line -hose
	Pressure reducing valve -with relief - pneumatic		Filter
	Non-return valve		Cooler -with coolant flow line indication
	One-way restrictor valve		Air dryer

ELECTRICAL DATA

GENERAL

Solenoid – an electro-mechanical device used as a control mechanism.
Modes of Action – 4 modes of action generally available:

1) Single-acting – solenoid acts in one direction only – spring return

2) Double-acting – solenoid acts in both directions of valve movement

3) Latching/reversing stroke – solenoid moves from one extremity to the other in response to successive electrical signals

4) Proportional – solenoid adopts a position according to the magnitude of the signal received.

General types – ***Direct solenoid*** – The armature or core of the solenoid is directly linked to the valve spool.
Pilot solenoid – Operates a small pilot valve which allows pressure to act upon the valve spool.

Technical Characteristics:-

Voltage – Generally 24v to 240v. Voltage tolerance – typically + or – 10%.

Power consumption – from 2 watts – miniature pilot type, up to 42 watts – large direct solenoid. Most solenoids are continuously rated, i.e. they can be energised for long periods.

Response times – Direct solenoid generally 10/12 milliseconds
– Pilot solenoid generally 25/40 milliseconds

Insulation class – indicates limiting temperature of coil material
– typically 'H' – 180°C.

Tropicalisation – indicates resistance of coil to insect attack, humidity etc.

Electrical connections – Terminal box – valve enclosure contains a permanent terminal block to which electrical wiring can be connected – frequently with conduit thread opening – solenoid body has a two or three pin socket which accepts a mating plug – see ISO 4400/BS 6361. Plug entry usually has a conduit thread and plugs are available with a variety of indicators to show if the solenoid is energised. Flying leads – some solenoids are provided with simple loose leads for connection to an external terminal block.

Manual overrides – Solenoid valves are often supplied with a manual override as standard, so that the valve can be operated independent of an electrical supply, e.g. for test purposes. For direct solenoids, the manual override is usually mechanical, acting direct on the valve member. For pilot solenoids, the pilot valve has a simple hand or tool operated switch, operation of which allows entry of pressure to act on the valve spool.

Protection class – indicates the resistance of the solenoid enclosure, terminal box and/or plug to entry of dirt, water etc. – typically IP65 or IP66 – the number is significant – see IEC 144/BS 5420

Explosive atmospheres – Special solenoid valves are required for use in explosive atmospheres and the areas of use are classified into "zones" of potential risk:

Zone 0 – risk of explosion is continuously present.
Zone 1 – risk is frequently present
Zone 2 – risk is not present under normal conditions, but is a possibility.

A flameproof or explosion proof valve for use in a Zone 2 area, may only require some modifications to the normal terminal block or plug and socket employed, to reduce the possibility of sparking.

Zone 0 and Zone 1 conditions will require a special valve and terminal box enclosure so that any explosion will be contained within the valve body. Such enclosures require special certification by Health and Safety Executive – see BS 4683, BS 5501 and BS CP 1003 (withdrawn).

Intrinsically safe solenoids are special low–power units which are operated in conjunction with special protective devices, such as Zener barriers. These reduce the power supply to such low levels that sparks cannot occur.

GENERAL FORMULAE

GENERAL

Hydraulic

a) PUMPS AND MOTORS

FLOW RATE (l/min) $Q = \dfrac{D.n}{1000}$

SHAFT TORQUE (Nm) $T = \dfrac{D.p}{20\pi}$

SHAFT POWER (kW) $P = \dfrac{T.n}{9554}$

HYDRAULIC POWER (kW) $P = \dfrac{Q.p}{600}$

b) CYLINDERS

PRESSURE (N/m^2) $p = \dfrac{F}{A}$

FLOW RATE (l /min) $Q = 60.A.v.10^3$

F = Force (N)
A = Area (m^2)
v = Velocity (m/s)
p = Pressure (bar)
D = Displacement (cm^3/rev)
n = rev per min

c) FLOW

FLOW (l/min) $Q \ \alpha \ \sqrt{\Delta p}$

ie, if you double the flow you get 4 times the pressure change

Δp = Pressure change (bar)

PRESSURE LOSS IN PIPES

Flow in l/min	Tube bore size in mm								
	5	7	10	13	16	21	25	30	36
1	0.69	0.22							
2	1.38	0.44							
3	2.07	0.66	0.17						
5	4.14	1.24	0.24						
7.5	6.55	1.72	0.31						
10		3.10	0.38	0.14					
15		5.38	0.69	0.21	0.08				
20			1.10	0.30	0.14				
30			2.21	0.69	0.25	0.04			
40				1.17	0.45	0.08	0.04		
50					0.59	0.12	0.07	0.03	
75					1.31	0.23	0.14	0.06	0.02
100						0.41	0.22	0.13	0.03
150							0.45	0.23	0.06
200								0.41	0.10
250									0.16

This chart gives the approximate pressure drop in smooth bore straight pipes, in bar per 3m length. Bends and fittings will increase the above pressure losses and manufacturers should be consulted for more accurate figures

Pneumatic

a) FLOW THROUGH PIPES:

$$\Delta p = \frac{1.6 \times 10^{8} \times (Q \times 10^{-3})^{1.85} \times L \times 10^{-3}}{d^{5} \times p}$$

Where

Δp = Pressure drop (bar)

Q = Free air flow (m^3/s) = l/s x 10^{-3}

L = Pipe length (metres)

GENERAL

b) VELOCITY THROUGH PIPES:

$$v = \frac{1273Q}{(p + 1)\, d^{2}}$$

Where

v = Flow velocity in metres/s

p = Initial pressure (bar)

d = Inside pipe diameter (mm)

If the free air flow is known, the minimum inside diameter to keep velocity below 6 m/s, can be found from: $d\ (mm) = \sqrt{\frac{212 \times Q}{(p + 1)}}$

For normal installations, where the pressure is about 7 bar gauge, this can be simplified to:

d (mm) should be greater than $5 \times \sqrt{Q}$

HYDRAULIC CYLINDERS

Output force and maximum rod lengths

Example: Knowing the output force required (200kN) and the pressure of the system (160 bar), connect Output force through pressure to cut cylinder diameter. **Answer:** 125 millimetres.

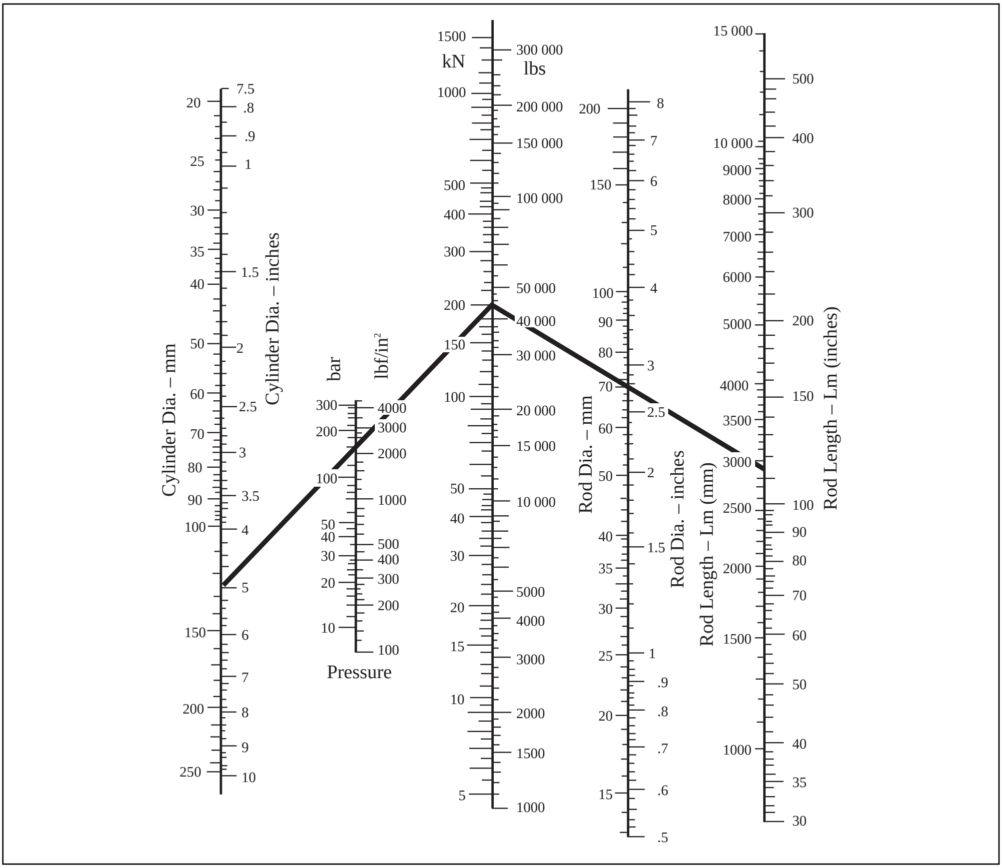
To find the maximum length of a piston rod. Connect output force required (200kN) through rod diameter (70mm) to cut the maximum rod length scale; this gives you the (Lm) dimension. **Answer:** 2800mm.

To find the actual length stroke (LA) for a specific mounting use formulae below.

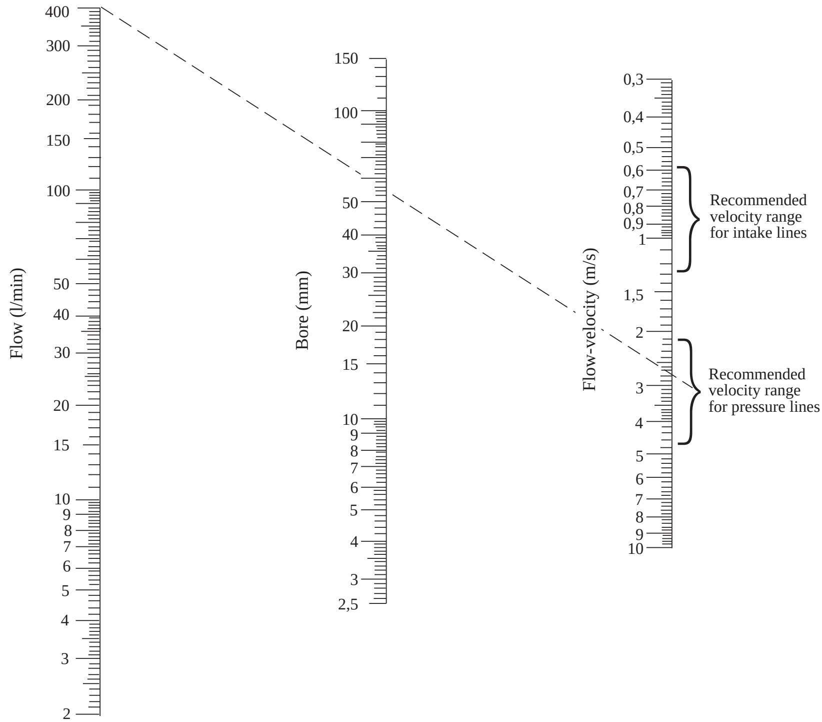
Maximum stroke lengths for specific mounting cases

Foot mounted, eye rod end	LA	=	Lm x 0.8
Foot mounted, rigidly supported rod	LA	=	Lm
Front flange, eye rod end	LA	=	Lm x 0.8
Front flange, rigidly supported rod	LA	=	Lm
Rear flange, eye rod end	LA	=	Lm x 0.4
Rear flange, rigidly supported rod	LA	=	Lm x 0.8
Rear eye, eye rod end	LA	=	Lm x 0.3
Trunnion head end, eye rod end	LA	=	Lm x 0.3
Trunnion gland end, eye rod end	LA	=	Lm x 0.6
Trunnion gland end, rigidly supported end	LA	=	Lm x 0.8

For intermediate trunnion positions scaled multiplier factors must be taken. Clevis and spherical eye mountings have the same factor as eye mountings.
Example: Having found Lm (2800mm) for rear flange mount with eye rod end
LA = Lm x 0.4 = 2800 x 0.4 = 1120mm.



HYDRAULIC PIPES AND HOSES



Nomogram for determining pipe sizes in relation to flow rates and recommended velocity ranges.

Based on the formula:

$$\text{Velocity of fluid in pipe(m/s)} = \frac{\text{Flow rate (l/min) x 21.22}}{d^2}$$

where d = Bore of pipe (mm)

Recommended velocity ranges based on oils having a maximum viscosity grade of 70cSt at 40°C and operating between 18°C and 70°C.

For further information, see :

BFPA/P7 – Guidelines to the selection and application of tube couplings for use in fluid power systems

BFPA/P47 – Guidelines for the use of fluid power hose assemblies.

HYDRAULICS

HYDRAULIC FLUIDS, SEALS AND CONTAMINATION CONTROL

FLUIDS

ISO Classification of Hydraulic Fluids - ISO 6743/4 (BS6413/4)

HH	Non inhibited refined mineral oils
HL	Refined mineral oils with improved anti-rust and anti-oxidation properties
HM	Oils of HL type with improved anti-wear properties
HV	Oils of HM type with improved viscosity/temperature properties
HFAE	Oil in water emulsions
HFAS	Chemical solutions in water
HFB	Water-in-oil emulsions
HFC	Water polymer solutions
HFDR	Synthetic fluids of the phosphate ester type
HFDS	Synthetic fluids consisting of chlorinated hydrocarbons

Ecologically Acceptable Hydraulic Fluids:

HETG	Tryglycerides
HEPG	Polyglycols
HEES	Synthetic Esters

Viscosity Classification of Hydraulic Fluids - ISO 3448 (BS 4231)

Each viscosity grade is designated by the nearest whole number to its mid-point kinematic viscosity in centistokes at 40°C. It is abbreviated ISOVG… Common viscosity grades of hydraulic fluids are VG5,10, 22, 32, 46, 68, 100, 150, 220 and 320.

Thus HM32 is a mineral oil with improved anti-rust, anti-oxidation and anti-wear properties having a viscosity of approximately 32 centistokes at 40°C.

For further details of specific fluids see BFPA/P12 - Mineral oil data sheets and BFPA/P13 - Fire resistant fluids data sheets, BFPA/P67 Ecologically acceptable hydraulic fluids data sheets

SEALS

Seal Material		Recommended for:
Acrylonitrile butadiene	**(NBR)**	air, oil, water, water/glycol
Polyacrylate rubber	**(ACM)**	air, oil
Polyurethane	**(AV, EU)**	air, oil
Fluorocarbon rubber	**(FPM)**	air, oil water, water/glycol, phosphate ester, chlorinated hydrocarbons
Silicone	**(FMQ)**	air, oil, phosphate esters, chlorinated hydrocarbons
Styrene Butadiene	**(SBR)**	air, water, water/glycol
Ethylene propylene diene	**(EPDM)**	air, water, water/glycol, phosphate ester
Polytetrafluorethylene	**(PTFE)**	air, oil, water, water/glycol, phosphate ester

"For full details of seal compatibilities, see ISO 6072: Hydraulic fluid power - Compatibility between elastomeric materials and fluids or BS 7714: Guide for care and handling of seals for fluid power applications. For recommendation of O-ring seal standards, see BFPA/P22 "Industrial O-ring Standards - Metric versus Inch."

Specification of Degree of Filtration - ISO 4572 (BS6275/1)

The multipass test, ISO 4572 (BS6275/1), was introduced to overcome the difficulties in comparing the performance of filters. The element is subjected to a constant circulation of oil during which time fresh contaminant (ISO Test Dust) is injected into the test rig. The contaminant that is not removed by the element under test is recirculated thereby simulating service conditions.
The filtration ratio ß of the filter is obtained by the analysis of fluid samples extracted from upstream and downstream of the test filter, thus

$$ßx = \frac{\text{number of particles larger than 'x' upstream of the filter}}{\text{number of particles larger than 'x' downstream of the filter}}$$

The rating of a filter element is stated as the micrometer size where 'ßx' is a high value (e.g. 100 or 200)

Fluid Cleanliness Standards

The preferred method of quoting the number of solid contaminant particles in a sample is the use of ISO 4406 (BS 5540).

The code is constructed from the combination of two range numbers selected from the following table. The first range number represents the number of particles in a millilitre sample of the fluid that are larger than 5 microns, and the second number represents the number of particles that are larger than 15 microns.

Number of particles per millilitre		Scale number
More than	up to and including	
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7

For example code 18/13 indicates that there are between 1,300 and 2,500 particles larger than 5 microns and between 40 and 80 particles larger than 15 microns.

For further details and comparisons of ISO 4406 with other cleanliness classes, see BFPA/P5 - Guidelines to contamination control in fluid power systems.

Flushing

Formula for flow required to adequately flush an hydraulic system;

$Q > 0.189\ \nu d$ litre/minute where

Q = flow (l/min)
ν = kinematic viscosity (cSt), and
d = pipe bore (mm)

For further information on flushing see BFPA/P9 - Guidelines to the flushing of hydraulic systems.

Cleanliness of Components

Three methods exist for measuring the cleanliness of components: test rig; flush test; strip and wash. The level of cleanliness required must be agreed between the supplier and customer but the methods are fully described in BFPA/P48 - Guidelines to the cleanliness of hydraulic fluid power components.

ACCUMULATORS

Storage Applications

Formula to estimate accumulator volume for storage applications.

Slow charge
Slow discharge

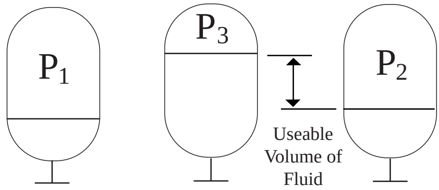
$$V_1 = \frac{Va \times \frac{p_2}{p_1}}{1 - \frac{p_2}{p_3}}$$

Fast charge
Fast discharge

$$V_1 = \frac{Va \times \left(\frac{p_2}{p_1}\right)^{\frac{1}{1.4}}}{1 - \left(\frac{p_2}{p_3}\right)^{\frac{1}{1.4}}}$$

Slow charge
Fast discharge

$$V_1 = \frac{Va \times \frac{p_3}{p_1}}{\left(\frac{p_3}{p_2}\right)^{\frac{1}{1.4}} - 1}$$



The precharge pressure is chosen to 90% of the min. working pressure. n varies between 1 and 1.4 depending on whether the charge is slow (isothermal) or fast (adiabatic).

Pump Pulsation

Formula to size accumulator to reduce pump pulsations.

a) Minimum effective volume (litres) $V_1 = \frac{k.\,Q}{n}$

Note: It is good engineering practice to select an accumulator with port connection equal to the pump port connection.

b) To check the level of pulsation obtained.
Volume of fluid entering accumulator = D . C

For pulsation damping precharge pressure $P_1 = 0.7 \,.\, P_2$
and assuming change from P_1 to P_2 is isothermal, then $V_2 = 0.7 \,.\, V_1$

$$V_3 = V_2 - (D \,.\, C)$$

$$P_3 = P_3 \left(\frac{V_2}{V_3}\right)^{1.4}$$

Hence: Percentage pulsation above and below mean is $\left(\frac{P_2 - P_3}{P_2}\right) 100$

V_1 = effective gas volume
V_2 = min. gas volume
V_3 = max. gas volume
p_1 = pre charge pressure
p_2 = min. working pressure
p_3 = max. working pressure

Va = $V_3 - V_2$ = working volume (fluid)
k = a constant*
Q = Pump flow (l/min)
n = Pump speed (rpm) if n > 100 use 100
D = Pump displacement (l/rev)
C = a constant*

* Dependent upon no. of pistons. For multi-piston pumps > 3 pistons. k = 0.45 and C = 0.013.

HYDRAULIC COOLING AND HEATING

COOLING

The tank cools the oil through radiation and convection.

$$P = \frac{\Delta T_1 . A . k}{1000}$$

where

k = 12	at normally ventilated space
24 W/m² °C	at forced ventilation
6	at poor air circulation

Required volume of water flow through the cooler:

$$Q = 860 \times \frac{\text{Power loss}}{\Delta T \text{ water}} \quad \text{l/Hr}$$

HEAT EQUIVALENT OF HYDRAULIC POWER

$$\text{in kJ/sec} = \frac{\text{Flow (l/min) x Pressure (bar)}}{600}$$

HEATING

Heating is most necessary if the environmental temperature is essentially below 0°C.

Requisite heating effect:

$$P = \frac{V . \Delta T_2}{35 . \Delta t} \quad \text{kW}$$

ENERGY

(J) = M.C. ΔT
M = Mass (kg)
C = Sp. ht. cap J/Kg°C
ΔT_1 = temp difference (°C) Fluid/Air
ΔT_2 = Increase in Fluid temp (°C)
Δt = time (min)

Note

1MJ = 0.2777 kW/hr

CHANGE OF VOLUME AT VARIATION OF TEMPERATURE

Change or volume ΔV = $6.3 \times 10^{-4} . V . \Delta T$

CHANGE OF PRESSURE AT VARIATION OF TEMPERATURE

Note: With an infinite stiff cylinder.

Change of pressure Δp = 11.8 . ΔT (in general – affected by many variables)

Example: The temperature variation of the cylinder oil from night time (10°C) to day time/solar radiation (50°C) gives:

ΔP = 11.8 x 40 = 472 bar

KEY

ΔT = Temp change (°C)
P = Power (kW)
k = heating coefficient (W/m² °C)
A = Area of tank excluding base (m²)
Δt = time change (min)
Δp = change in pressure (bar)
C = Specific heat capacity (J/kg°C)
V = Volume (l)

HYDRAULICS

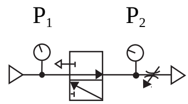
PNEUMATIC VALVE FLOW

Valve flow performance is usually indecated by a flow factor of some kind, such as “C”, “b”, “Cv”, “Kv”, and others.
The most accurate way of determining the performance of a pneumatic valve is through its values of “C” (conductance) and “b” (critical pressure ratio).
These figures are determined by testing the valve to the CETOP RP50P recommendations.
The tests will result typically in a set of curves as shown below.
From these the critical pressure ratio “b” can be found. “b” represents the ratio of P2 to P1 at which the flow velocity goes sonic (the limiting speed of air). Also the conductance “C” which represents the flow “dm^3/second/bar absolute” at this point.

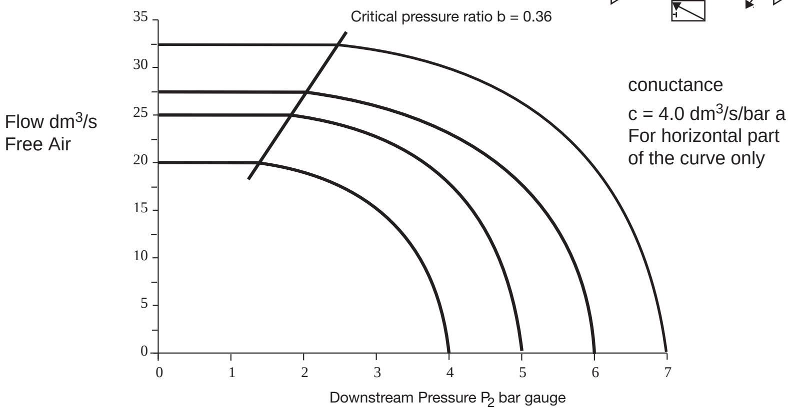
If a set of curves are not available the value of flow for other pressure drops can be calculated from

$$Q = C\,P1\sqrt{1-\left[\frac{\frac{P2}{P1}-b}{1-b}\right]^2}$$

Where P1= upstream pressure bar; P2= downstream pressure bar
C = conductance dm^3/s/bar a; b = critical pressure ratio
Q = flow dm^3/s



ISO 6538/CETOP RP50P Method



PNEUMATIC CYLINDERS

Some factors to consider when selecting and using pneumatic linear actuators – air cylinders

Mode of action: Three basic types –

Single-acting, spring return Movement and force by air pressure in one direction, return movement by internal spring force – usually sprung to outstroke position but occasionally the reverse is available. To save air and overcome availability problems, a double–acting cylinder may be used, in a single–acting mode, with low pressure constantly supplied to one end.

Double-acting Air pressure required to produce force and movement in both directions of travel.

Double-acting, through rod Double–ended piston rod which acts as a normal double–acting cylinder, but mechanical connections can be made to both ends of through rod.

Rodless Cylinders : Where space is at a premium and there are potential loading and alignment problems, a variety of rodless cylinder designs are available. The range of available bore sizes is limited eg 16 – 100mm.

Quality Classes: Basically three qualities of unit available –

Light Duty and Compact cylinders Limited range of bore sizes, up to 100mm. Not cushioned at stroke ends, or cushion pads only. Check manufacturers data sheets for serviceability and susceptibility to corrosion.

Medium Duty/ Standard For normal factory environments. Some degree of corrosion resistance. Serviceable. Cushioned at both ends. Usually double-acting. Bore size range, 32mm and greater.

Heavy Duty Rugged construction. Serviceable. Non-corrodible materials. superior cushioning – thicker piston rods and heavy duty mountings. bore size range 32mm and greater.

For interchangeability and standard mounting dimensions, see ISO 6432, 8 to 25mm bore,
ISO 6431, 32 to 320 bore - standard duty, double-acting, metric dimensions.

Standard Bore sizes:

Double-acting 8, 10, 12, 16, 20, 25, 32, 40, 50, 63, 80, 100, 125, 160, 200, 250 and 320mm.

Standard, Stocked Strokes:

Double-acting 25, 50, 80, 100, 125, 160, 200, 250 and 320mm.

Cylinder Thrust: To calculate the theoretical thrust of a double-acting cylinder, use the formula:

Thrust $= \left(\frac{\pi D^2 \times P}{40}\right)$ newton where D = diameter of piston (mm) P = Gauge pressure (bar)
Pull will be less, due to area of piston rod.

Pull = $\left[\frac{\pi (D^2 - d^2) \times P}{40}\right]$ newton where d = diameter of piston rod (mm).

For static loading, ie where full thrust is only required when the cylinder comes to rest, eg clamping – use the above calculation.
For dynamic loading, ie where thrust is required throughout the piston travel, allowance has to be made for the exhaust back-pressure, friction, changes in driving pressure, etc – add 30% to the thrust figure required, for normal speeds. For higher speeds add 100%.

Cylinder Speeds: With normal loading, valving and pressure – 5-7 bar, the important factor is the relationship between the bore area of the cylinder and the actual bore area of the cylinder inlet ports.Conventionally this is in the order of 100:1 and would result in speeds of 0.3 – 0.5 metres per second. For normal speeds, use a directional control valve and piping of the same size as the cylinder ports. For higher speeds use a cylinder of larger bore size than necessary plus larger valve and pipework but be careful of cushioning problems.

Stroke Lengths: For static loading use any convenient standard, stocked stroke length as cushioning is not important. For dynamic loading, order the correct required stroke length as the use of external stops affects cushioning potential.
With long stroke lengths, i.e. more than 15 x bore diameter, care must be taken to avoid side-loading on bearing, etc. – use pivot type mountings. Check diameter of piston rod to avoid buckling under load. If necessary use a larger bore size cylinder than normal as this will probably have a longer bearing and a thicker piston rod.

SEALS, FILTRATION AND LUBRICATION

SEALS:

Some miniature pneumatic components and heavy duty valves employ metal to metal sealing. Most equipment uses flexible seals manufactured from synthetic rubber materials. These are suitable for ambient temperatures up to 80°C. Viton or silicon rubber seals are used for temperatures up to 150°C.

Synthetic seals are resistant to mineral based hydraulic oils but specific types of oil must be checked with the equipment manufacturer to avoid problems arising from additives. (see page 14)

Good wear resistance ensures a reasonable performance, even with a relatively wet and dirty air supply. However, to ensure safe operation, with a satisfactory service life, system filtration and some form of lubrication is necessary.

FILTRATION:

Good filtration starts at the compressor with correct siting of the air intake and an intake filter. Errors at this stage cause problems throughout the subsequent installation. Aftercoolers and dryers ensure that the supply enters the ring main in good condition, but condensation and dirt can be picked up on the way to the point of use. Individual filters are necessary at each major application point.

For general industrial purposes, filters with a 40 micron (micrometre) element are satisfactory. For instrument pneumatics, air gauging, spraying etc, a filter of 5 micron or better is required. High Quality filters are often called coalescers. Filters are available with manual, automatic or semi-automatic drain assemblies.

To alleviate the problem of dirt entering open exhaust ports use an exhaust port silencer which also avoids noise problems. Simple exhaust port filters are also available, which offer a reasonable level of silencing, with little flow resistance.

LUBRICATION:

Most industrial air supplies contain a little moisture and all pneumatic components are greased on assembly, unless specifically requested otherwise. This provides significant lubrication and ensures that the equipment performs satisfactorily for several million cycles, particulary if used frequently.

An airline lubricator is the best solution for most industrial applications. These fall into two categories: **oil-fog** lubricators for larger pipe sizes, over 25mm bore, high flows and short distances, up to 9 metres and **micro-fog** lubricators which provide a smaller droplet size, necessary for longer pipe runs and complex systems. Lubricator sizing is important to ensure sufficient capacity to cope with any high instantaneous demands created by the application.

CONDITIONING UNITS:

Air conditioning units (FRLs), consisting of a filter, pressure regulator and lubricator in series, offer the best solution to most application problems. Various combinations are available. Modern FRLs employ some form of manifold construction to ensure easy maintenance.

COMPRESSORS

As most industrial factory and machine-shop type pneumatic equipment operates at about 6 bar, it is usual to select a compressor installation delivering 7 bar in to the mains, to allow for pipe losses.

Types of Compressor:

Displacement Compressors Air is compressed by contracting the space containing air taken in at atmospheric pressure eg reciprocating compressors – piston or diaphragm type; rotary compressors – sliding vane, gear, screw. Roots blower.

Dynamic Compressors Compression is achieved by converting the air inlet rate into a pressure, e.g. centrifugal compressors – radial impeller, blade type, axial compressors.

Overlap occurs between the various types in terms of capacity and pressure range but some generalisation can be made. Use reciprocating compressors if very high pressures, up to 1000 bar are required. Rotary vane types are used for medium pressures, up to 7 bar and low capacity. Blowers are used for large volumes of low pressure air, up to 1 bar.

For industrial applications compressors can be classified–

Sizes:

Small – up to 40 l/s
Medium – 40l/s to 300 l/s
Large – above 300 l/s

Three types of installation dependant on application –

Installation:

Portable Paint spraying, tyre inflation, etc.
Mobile Road/rock drills, rammers, emergency stand-by sets, etc.
Fixed Machines, factory, workshop, etc.

Prime Movers: Selection of correct drive unit is essential to obtain efficient and economical supply. Three basic types – **Electric Motors** are used for compactness and ease of control; **IC Engine** (diesel, petrol, gas) for mobile units, emergency stand-by sets or where an electrical supply is not available; **Turbine** (gas, steam) can be incorporated into the total energy system of a plant using existing steam or gas supplies.

Selection Factors:

Delivery Pressure Must be high enough for all existing and potential future requirements. If there is a special requirement for a large volume of either high or low air pressure, it may be better to install a separate unit for that purpose.

Capacity Calculate not only the average air consumption but also maximum instantaneous demands, e.g. large bore cylinders and air motors, operating at high speeds. Determine use factors. Frequently users add to existing airlines indiscriminately and run out of air.

Intake Siting Intake air should be as clean and as cold as possible for maximum efficiency.

Intake Filter High capacity to remove abrasive materials which could lead to rapid wear.

Air Quality Study air quality requirements throughout the system or plant. The correct combinations of separators, aftercoolers, outlet filters and dryers should be determined. The problem of water removal should not be left to the airline filters associated with individual plant and systems.

Stand-by Capacity What would happen in an emergency or when an individual compressor requires servicing

Air Receiver The system must have adequate storage requirements, not only to meet demand, but also to ensure efficient running of the prime mover.

Air Main Capacity A large bore ring main acts as a useful receiver, reduces pressure drops and operating costs. The cost of larger size of pipework is only a small proportion of the installation costs.

BFPA The British Fluid Power Association

BFPA promotes the technical, trade and commercial interests of the BRITISH FLUID POWER INDUSTRY

BFPA provides -

- a meeting place within the industry;
- technical standards and guidelines for the industry;
- representation of industries and other trade organisations;
- exhibition organisation and sponsorship;
- group stands and information centres at major UK customer exhibitions;
- export promotion via overseas missions and exhibitions;
- marketing and statistical data;
- research project management;
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- European co-operation
- and an information advisory centre.

Membership is open to manufacturers and suppliers of hydraulic and pneumatic equipment, consultants, teaching and research establishments.

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