Technical Service Data

Practical planning of hydraulic equipment

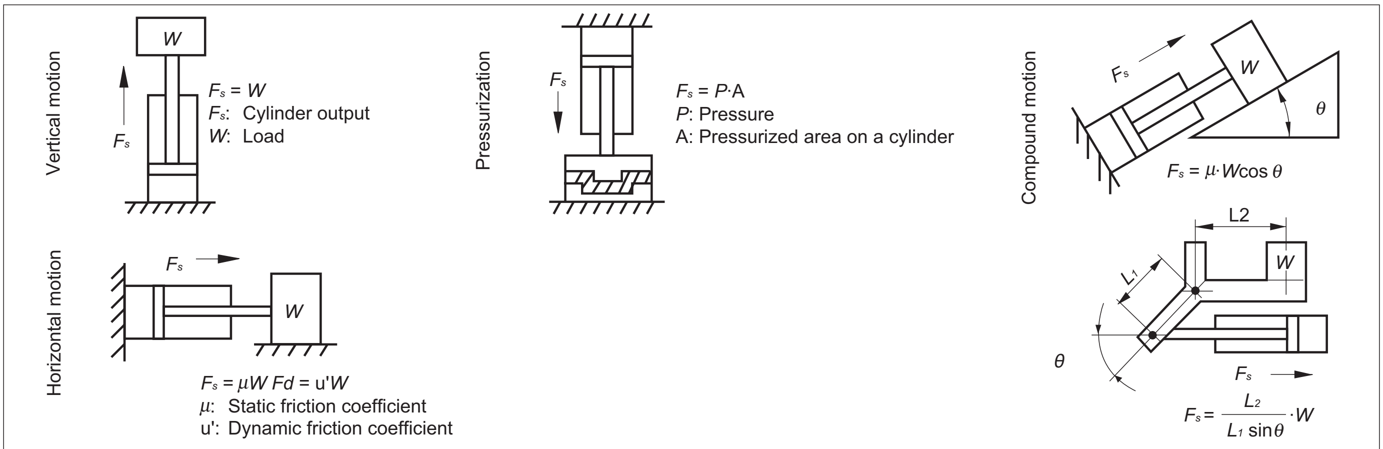
The following illustrates the specifications of the main machine that need to be clarified in advance to draw out a scheme for a hydraulic unit, and how to obtain values related to those specifications.

● Load Analysis

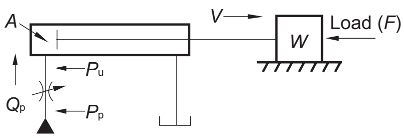
With general resistance loads, the load can be analyzed by obtaining the maximum output by drawing the schematic diagrams as shown below.

Note, however, that accelerating force will also be required in addition to the resistance load in an application where an object is moved.

	International system of units	Engineering system of units
Maximum output required for a cylinder F	F = Fs + fd (N) Fs: Resistance load (N) fd: Accelerating force (N) fd = mα = m·V/t (N) m: Mass (kg) α: Acceleration (m/s^2) t: Acceleration time (s) V: Velocity (m/s)	F = Fs + fd (kgf) Fs: Resistance load (kgf) fd: Accelerating force (kgf) fd = mα = W/g·V/t (kgf) m: Mass (kgf·s^2/m) α: Acceleration (m/s^2) W: Load (kgf) g: Gravitational acceleration: 9.8 m/s^2 t: Acceleration time (s) V: Velocity (m/s)



● Calculation of hydraulic cylinder properties

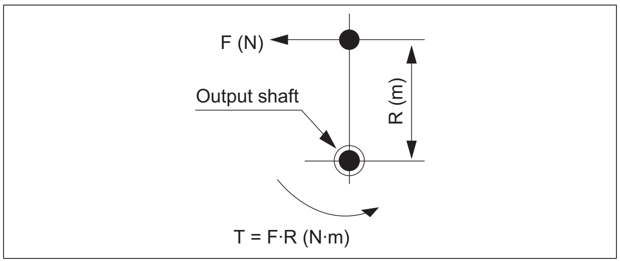


	International system of units	Engineering system of units
Cylinder net required pressure Pu	Pu = F / A × 10^{-2} (MPa) F: Load (N) A: Pressurized area on a cylinder (cm^2)	Pu = F / A (kgf/cm^2) F: Load (kgf) A: Pressurized area on a cylinder (cm^2)
Pump required pressure Pp	Pp = Pu + ΔP (MPa) ΔP: Pressure loss in valves/piping (MPa)	Pp = Pu + ΔP (kgf/cm^2) ΔP: Pressure loss in valves/piping (kgf/cm^2)
Cylinder net required flow rate Qc	Qc = A·V·6 (L/min) A: Pressurized area on a cylinder (cm^2) V: Velocity (m/s)	
Pump required discharge rate Qp	Qp = Qc + ql (L/min) ql: Flow rate loss (L/min) (Rate of leakage from valves, cylinders, etc.)	

Technical Service Data

● Calculation of hydraulic motor properties

	International system of units	Engineering system of units
Output torque T	$T = \dfrac{P \cdot q}{2 \cdot \pi} \times \eta t$ (N·m) P: Pressure difference between motor inlet and outlet (MPa) q: Inflow per motor revolution (cm^3/rev) ηt: Torque efficiency of motor (%)	$T = \dfrac{P \cdot q}{2 \cdot \pi \times 100} \times \eta t$ (kgf·m) P: Pressure difference between motor inlet and outlet (kgf/cm^2) q: Inflow per motor revolution (cm^3/rev) ηt: Torque efficiency of motor (%)
Shaft output L	$L = \dfrac{2 \cdot \pi \cdot N \cdot T}{60000}$ (kW) N: Output shaft speed (min^{-1})	$L = \dfrac{2 \cdot \pi \cdot N \cdot T}{6120}$ (kW) N: Output shaft speed (min^{-1})

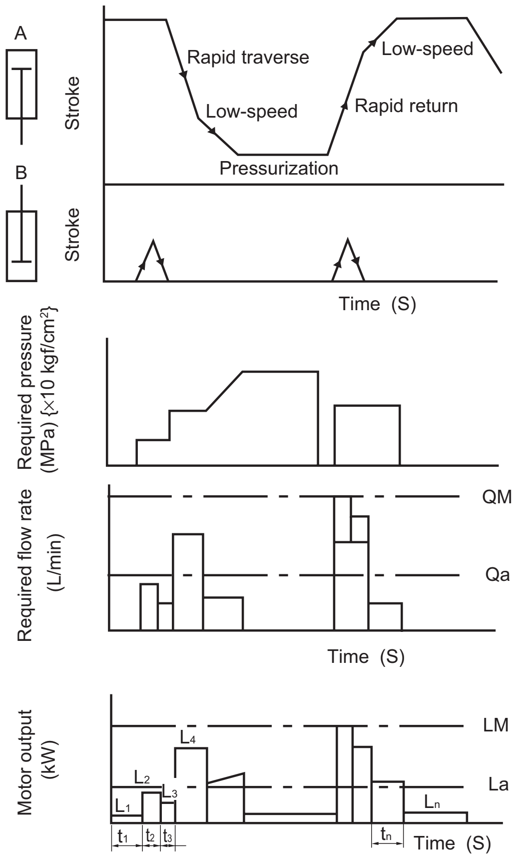


● Calculation of accumulator

Accumulators are commonly used for purposes such as: (1) Energy accumulation (2) Impact buffering (3) Pulsation absorption (4) Shock absorbing (5) Counter balancing (6) Transfer barrier (7) Pressure holding

○ Energy accumulation

In the method generally used, the discharge rate of the pump is determined by calculating the volume of fluid required for the entire operation cycle concerned.
The use of an accumulator to compensate for insufficient oil supply from the pump helps to minimize the pump size. However, this makes it necessary to check for pressure drops when fluid is discharged, and whether there is sufficient time to build the required pressure in the operation cycle.
Create a fluid volume table according to the operation cycle to determine the discharge rate of the pump.



Maximum volume of fluid required QM
If the maximum volume of fluid required is to be covered by the pump alone, a large pump, motor and fluid tank will be required.

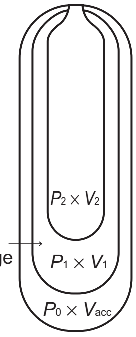
Average fluid volume Qa
The volume required beyond the average fluid volume is to be compensated for by an accumulator.

Maximum motor output LM
If the motor size is determined based on the maximum motor output required, a large motor will be required.

Average motor output La
By determining the motor size according to the root-mean-square output, it can be kept compact. Note, however, that the overload at peak will take place at the stalling torque of 160% (within 15 seconds) or higher according to the JEC37 standard.

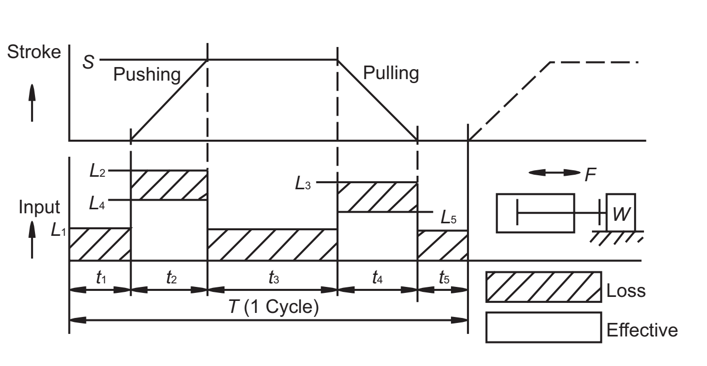
$$La = \sqrt{\frac{(L_1^2 \times t_1) + (L_2^2 \times t_2) + \cdots\cdots\cdots (Ln^2 \times tn)}{t_1 + t_2 + \cdots\cdots\cdots + tn}}$$

Technical Service Data

	SI system of units	Engineering system of units
Accumulator required volume Vacc  	$Vacc = \dfrac{V}{\dfrac{P_0}{P_1} \times \dfrac{\left(\dfrac{P_2}{P_1}\right)^{\frac{1}{n}} - 1}{\left(\dfrac{P_2}{P_1}\right)^{\frac{1}{m}}} \times \eta acc}$ P_0: Charged gas pressure (MPa) P_1: Minimum operating pressure (MPa) P_2: Maximum operating pressure (MPa) v: Effective discharge volume from P_2 to P_1 (L) m, n: Polytropic index (1.4 to 1.9) ηacc: Efficiency of accumulator (0.95)	$Vacc = \dfrac{V}{\dfrac{P_0}{P_1} \times \dfrac{\left(\dfrac{P_2}{P_1}\right)^{\frac{1}{n}} - 1}{\left(\dfrac{P_2}{P_1}\right)^{\frac{1}{m}}} \times \eta acc}$ P_0: Charged gas pressure (kgf/cm^2) P_1: Minimum operating pressure (kgf/cm^2) P_2: Maximum operating pressure (kgf/cm^2) v: Effective discharge volume from P_2 to P_1 (L) m, n: Polytropic index (1.4 to 1.9) ηacc: Efficiency of accumulator (0.95)

● Heat balance

○ Controlling the temperature of hydraulic fluid within the appropriate range (15 to 50°C) is a significant issue since the entire power loss in the hydraulic system is converted to heat and causes many kinds of trouble by increasing the temperature of the hydraulic fluid.
A temperature rise beyond 60°C not only shortens the service life of hydraulic fluid but also causes generation of contaminants, leading to failure or shorter service lives of the pump and other hydraulic devices.



	International system of units	Engineering system of units
Heat generated He	He = 3600 × (Li – Lu) (kJ/h) Li: Pump axial input (kW) Lu: Actuator's effective input (kW) L_1: Axial input at dead heading (or unloading) (kW) (To be calculated based on the pump brochure) L_2, L_3: Pump axial input Ln = Pn·Qn / 60 + Ls (n) (kW) Pn: Pressure (MPa) Qn: Flow rate (L/min) Ls: Power loss (kW) (From pump data) L_4, L_5: Effective work Ln = Fn·Sn Fn: Load (N) Sn: Stroke (m) Average pump axial input $Li = (L_1 \cdot t_1 + L_2 \cdot t_2 \cdots + L_1 \cdot t_5) / T$ (kW) Average effective input $Lu = (L_4 + L_5) / 1000T$ (kW) T: Time for 1 cycle (s)	He = 860 × (Li – Lu) (kcal/h) Li: Pump axial input (kW) Lu: Actuator's effective input (kW) L_1: Axial input at dead heading (or unloading) (kW) (To be calculated based on the pump brochure) L_2, L_3: Pump axial input Ln = Pn·Qn / 612 + Ls (n) (kW) Pn: Pressure (kgf/cm^2) Qn: Flow rate (L/min) Ls: Power loss (kW) (From pump data) L_4, L_5: Effective work Ln = Fn·Sn Fn: Load (kgf) Sn: Stroke (m) Average pump axial input $Li = (L_1 \cdot t_1 + L_2 \cdot t_2 \cdots + L_1 \cdot t_5) / T$ (kW) Average effective input $Lu = (L_4 + L_5) / 102T$ (kW) T: Time for 1 cycle (s)

Technical Service Data

	SI system of units	Engineering system of units
Tank heat emission Ho	Ho = A·K·ΔT (kJ/h) A: Tank surface area (m^2) K: Heat transfer coefficient 41.9 to 62.8 (kJ/h·m^2·°C) ΔT: Oil temperature – Ambient temperature (°C)	Ho = A·K·ΔT (kcal/h) A: Tank surface area (m^2) K: Heat transfer coefficient 10 to 15 (kcal/h·m^2·°C) ΔT: Oil temperature – Ambient temperature (°C)
Heat balance He	Hc = He – Ho (kW/h) He ≤ 0: Cooler not required He > 0: Cooler required	

○ Notes on heat balance calculation

- The calculation of the tank heat emission assumes the fluid temperature in the tank to be 60°C maximum for general-purpose hydraulic fluid (R&O) and 55°C maximum for water-glycol hydraulic fluid.
- When calculating the effective work of a cylinder with the same load applied in the upward and downward motion or no load applied in the upward motion and a load applied in the downward motion in addition to the self-weight load, pay attention since the resulting effective work will be zero or a negative value, i.e. external power loss is imposed.
- Be careful when using a valve with large volume of drainage such as a reducing valve, even in the full cutoff state.

● Notes on planning of hydraulic equipment

○ Environmental conditions

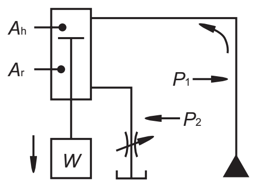
- Temperature At 50°C or higher: Care heat emission and the rating limits of electrical devices.
  At 0°C or lower: Care the suction capacity limit of the pump.
- Humidity At 95% or higher: Care the humidity resistance limit of electrical devices.
- Dust In an environment with a lot of dust, countermeasures such as an enhanced air breather or air tightness is necessary.

○ Standards, Laws and Regulations in Japan

- Tank The Fire Service Act applies when the oil volume within a unit or a total of the oil volumes of units on the same floor reaches 6000 L. It may also apply with a smaller oil volume depending on local regulations.
- Accumulator Care the applicability of regulations for high-pressure gas.
- Standards JIS, ISO (threads), JEM (electrical devices)

● Notes on designing hydraulic circuits

○ Pressure increase with meter-out throttle

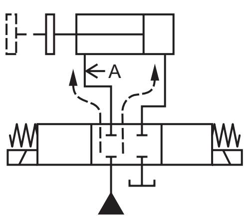


Use of a meter-out throttle as shown in the figure to the left increases the pressure. Especially when the cylinder is directed downward and there is a hanging load however, abnormal pressure at the rod side may occur.

$P_2 = (P_1 \cdot Ah + W) / Ar$ (MPa {×10 kgf/cm^2})

Countermeasure:
- Use of devices, piping and hoses design for high-pressure applications
- Counter balance circuit
- Reduction of pressure at the head side

○ Self-propelling in very slow due to leakage at a directional control valve



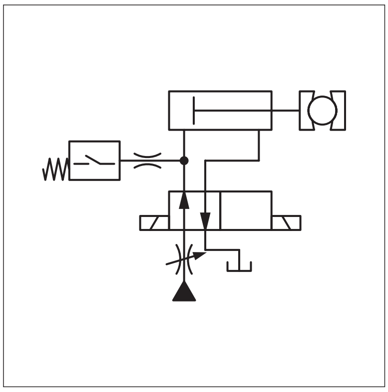
The cylinder may be self-propelled in very slow speed due to leakage at a directional control valve in a circuit as shown in the figure to the left where the load to the cylinder is light and the pressure within the line is retained.

Countermeasure: Install a pilot check valve at A in the figure.

Technical Service Data

● Notes on designing hydraulic circuits

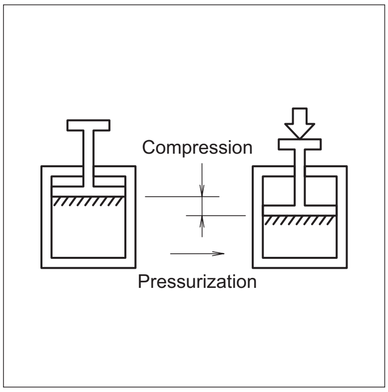
○ Malfunction of pressure switch



The pressure switch may malfunction due to surge pressure on excitation of a solenoid valve in a circuit as shown in the figure to the left.

Countermeasure:
- Throttle the gauge damper
- Interlock the pressure switch with a timer

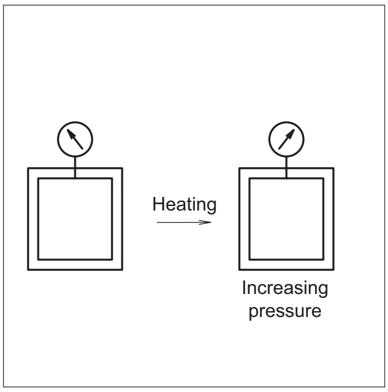
○ Shockless pressure relief



Hydraulic fluid has a small compressibility compared to air but its volume will be reduced by 1% on application of a pressure of 20 MPa {200 kgf/cm^2}.
For this reason, sudden switching of a solenoid valve may cause a shock.

Countermeasure:
- Switch the solenoid valve slowly
- Insert a pressure relief circuit

○ Pressure increase due to heating (Pressure decrease due to cooling)



Heating hydraulic fluid within an airtight container will expand the fluid and increase the pressure.
Conversely, cooling the fluid will decrease the pressure.
A temperature change of 1°C leads to a pressure change of 1 MPa {10 kgf/cm^2}.

Countermeasure:
- Install a safety valve
- Install an accumulator

Technical Service Data

Hydraulic cylinder selection

Although the sizes of appropriate cylinders can be calculated with the "Practical planning" mentioned on F2 "Practical planning of hydraulic equipment", this section illustrates the types of general cylinders and their selection method based on the Japanese Industrial Standards. For final confirmation, be sure to check the instruction manual provided by the relevant cylinder manufacturer.
Related Japanese Industrial Standards: JIS B 8367, JIS B 8366

Step 1: Selection of the cylinder and rod diameter

Obtain the diameter of the cylinder and the rod diameter through load analysis and calculation of the hydraulic cylinder size. Then, select from the general cylinders shown in the table below. Generally, type B cylinders (with rod B) are commonly used.

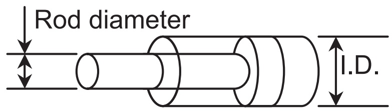


Table: General cylinder inner diameters and rod diameters

Cylinder diameter (mm)			32	40	50	63	80	100	125	140	160	180	200	224	250
Rod diameter mm	Type A		22.4	28	35.5	45	56	71	90	100	112	125	140	160	180
	Type B		18	22.4	28	35.5	45	56	71	80	90	100	112	125	140
	Type C		14	18	22.4	28	35.5	45	56	63	71	80	90	100	112
Pressurized area cm^2	Pushing		8.0	12.6	19.6	31.2	50.3	78.5	122.7	153.9	201.1	254.5	314.2	394.1	490.9
	Pulling	Type A	4.1	6.4	9.7	15.3	25.6	38.9	59.1	75.4	102.5	131.8	160.2	193.0	236.4
		Type B	5.5	8.6	13.5	21.3	34.4	53.9	83.1	103.7	137.4	175.9	215.6	271.4	336.9
		Type C	6.5	10.0	15.7	25.0	40.4	62.6	98.1	122.8	161.5	204.2	250.5	315.5	392.4
Rough speed range mm/s			8 to 400				8 to 300			8 to 200					
Rough maximum stroke mm			1200			1600		2000							

Reference: Some of the cylinder inner diameters and rod diameters given in the table above do not conform to JIS B 8367 but are more commonly used values (Value in the table JIS: 22.4 → 22, 35.5 → 36, 71 → 70, 112 → 110, 224 → 220).

<Operating speed>
Check if the operating speed of the cylinder is within the speed range given in the table above (See the instruction manual provided by the relevant cylinder manufacturer for final confirmation). Be careful because excessive or insufficient operating speed leads to deterioration of the sealing on the sliding parts and causes internal leakage. If the cylinder needs to be operated at a speed out of the range, the sliding parts must be treated carefully.

<Stroke>
As for the stroke, the cylinder should be selected within the maximum stroke range in the above table (the instruction manual provided by the cylinder manufacturer to be checked for final confirmation), and perform the buckling calculation indicated in Step 3.

<Pressure specifications>
Select the nominal pressure series based on the operating pressure of the cylinder.
(Examples of nominal pressure: 3.5 MPa, 7 MPa, 10 MPa, 14 MPa, 16 MPa, 21 MPa, etc.)
Cylinder manufacturers classify their products by the nominal pressure into product series. Select an appropriate product series.

<Minimum operating pressure>
Cylinders do not operate when the pressure is too low (guide: 0.5 MPa minimum at the head side and 1 MPa minimum at the rod side). Check the minimum operating pressure of each cylinder and use it at the minimum operating pressure or higher. Note that the minimum operation pressure may be larger than the guide given here depending on the nominal pressure, rod diameter, packing shapes, or other conditions.

Technical Service Data

Step 2: Support type selection

Check how the cylinder and the ends of the cylinder will be fixed to the main machine and select an appropriate cylinder support type on the table below.
When calculating the maximum length L, take the flanges at cylinder end into account.

Table: Buckling calculation parameters with general cylinder support types and rod ends 1

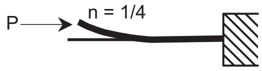
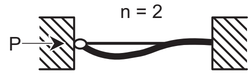
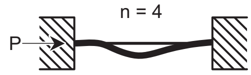
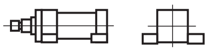
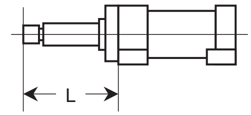
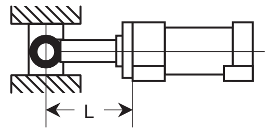
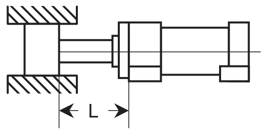
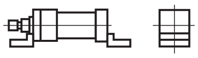
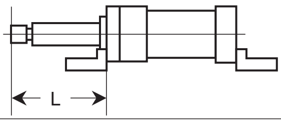
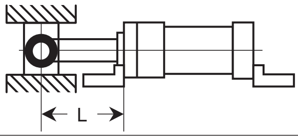
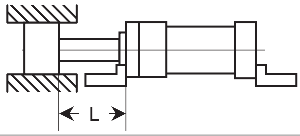
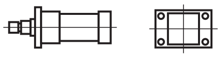
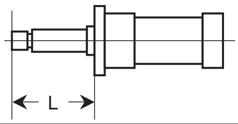
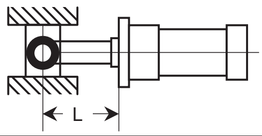
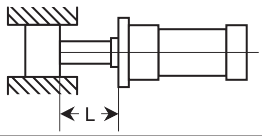
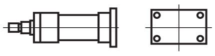
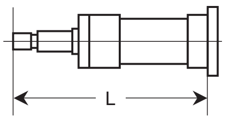
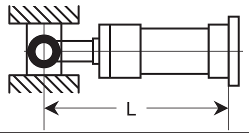
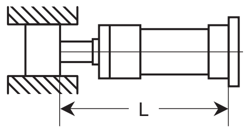
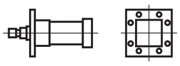
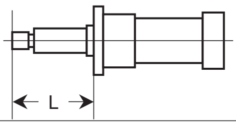
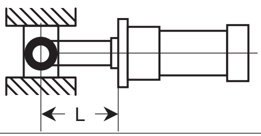
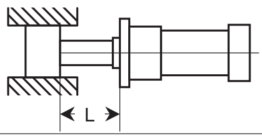
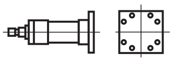
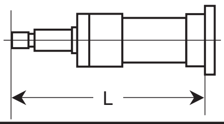
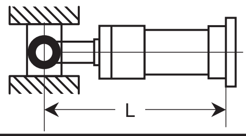
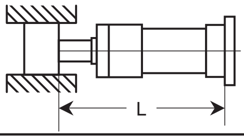
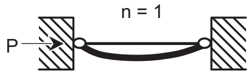
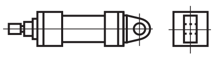
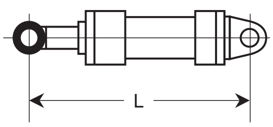
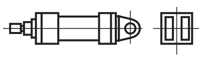
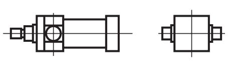
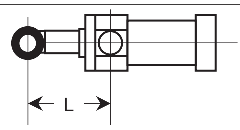
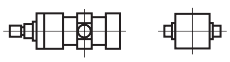
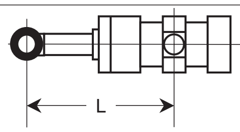
Support type	Name and sketch	Buckling calculation parameters n: Terminal coefficient L: Maximum length		
		n = 1/4 	n = 2 	n = 4 
LA	Perpendicular-to-axial-direction foot type 			
LB	Axial-direction foot type 			
FA	Rod side Rectangle flange type 			
FB	Head side Rectangle flange type 			
FC	Rod side Square flange type 			
FD	Head side Square flange type 			

Table: Buckling calculation parameters with general cylinder support types and rod ends 2

Support type	Name Schematic	Buckling calculation parameters n: Terminal coefficient L: Maximum length
		n = 1 
CA	Single crevice type 	
CB	Dual crevice type 	
TA	Rod side trunnion type 	
TC	Middle trunnion type 	

Technical Service Data

Step 3: Buckling calculation

If the maximum length of a cylinder is long compared to cylinder thickness and a load exceeding the limit is applied to the cylinder, the cylinder may buckle (yield under the force and bend), leading to a serious accident.
The procedure for obtaining the permissible load of cylinders is given below. However, be sure to check the instruction manual provided by the cylinder manufacturer to confirm the selection results.

<Calculation procedure>

(1) Obtain the maximum length L and terminal coefficient n based on the rod diameter and support type by the procedure given on the previous page.
(2) Obtain the slenderness ratio λ (= 4 L/d).
(3) Obtain the buckling load Wk by applying Euler's formula when the maximum length is relatively large (when the slenderness ratio exceeds $85\sqrt{n}$) or applying Rankine's formula when it is relatively small.
(4) Obtain the permissible load W by dividing the buckling load Wk by the safety factor.
(5) If the cylinder load is within the permissible load, it is judged as good.

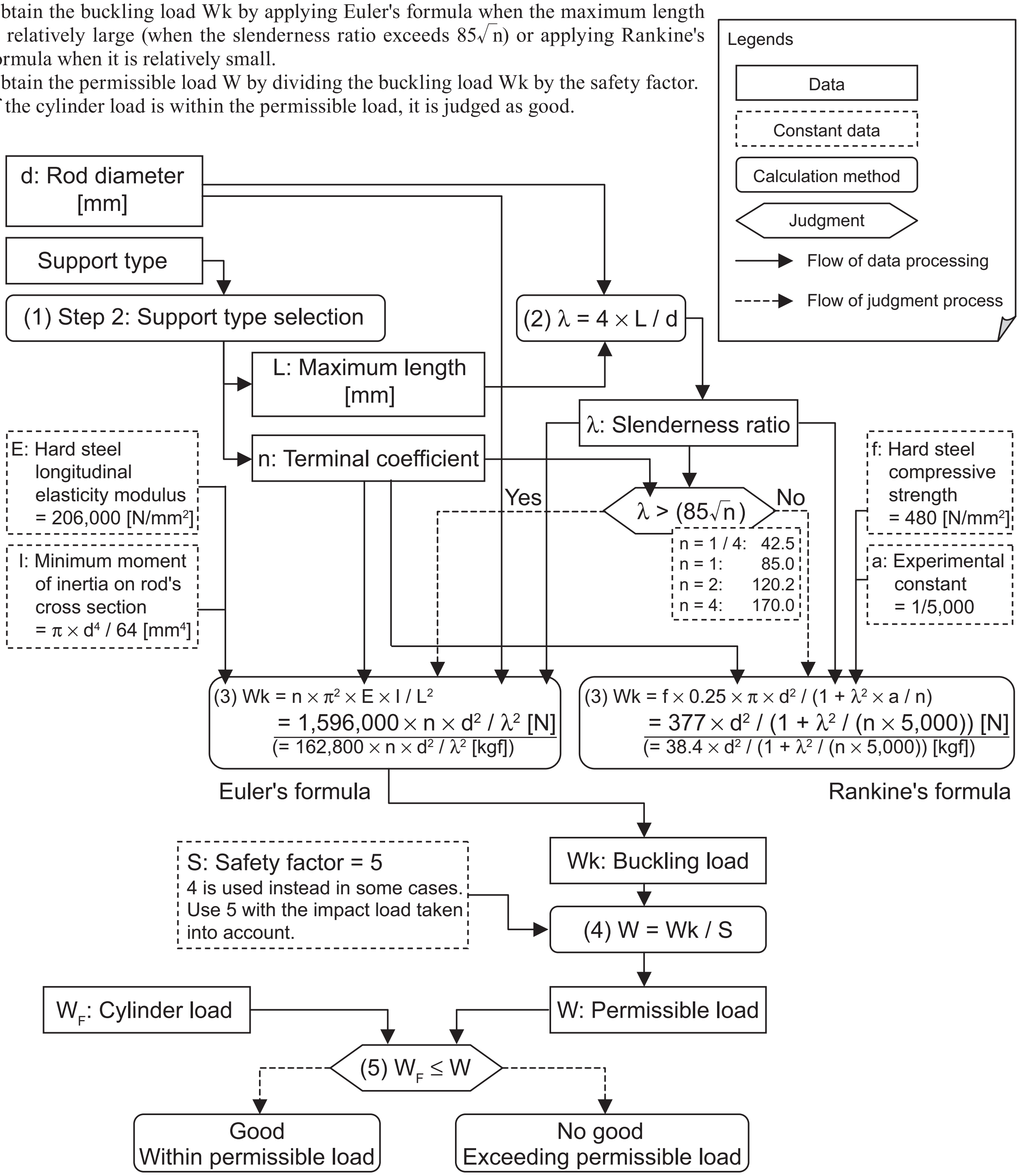


Figure: Flow of buckling calculation

Technical Service Data

Step 4: Packing material selection

Check the type of hydraulic fluid and select an appropriate packing material by referring to the table below.

Table: General hydraulic fluid types and applicability of packing materials

Packing material	Hydraulic fluid					
	Petroleum-based	Water-glycol	Phosphate ester	Fatty acid ester	Water/oil emulsion type	Oil/water emulsion type
Nitrile rubber	Usable	Usable	Unusable	Check individually	Usable	Usable
Urethane rubber	Usable	Unusable	Unusable	Check individually	Check individually	Check individually
Fluorine rubber	Usable	Check individually	Usable	Check individually	Usable	Usable

Step 5: Selection of other options

- Cushions
  Cushions for absorbing shocks on stopping at the extend/retract ends of the cylinder can be selected.
- Dust-proof covers
  The dust-proof cover (bellows) that protects the cylinder rod from dust can be selected.

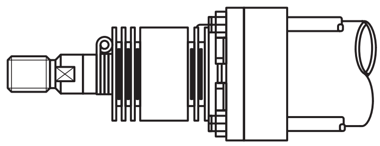


Figure: Dust-proof cover

- End bracket
  End bracket can be selected according to how the cylinder is fixed to the main machine.
  Calculate the value L in buckling carefully because it may vary depending on the end bracket selection.

Single end (T-shaped end) (Rod eye)

Dual ends (Y-shaped end) (Rod crevice)

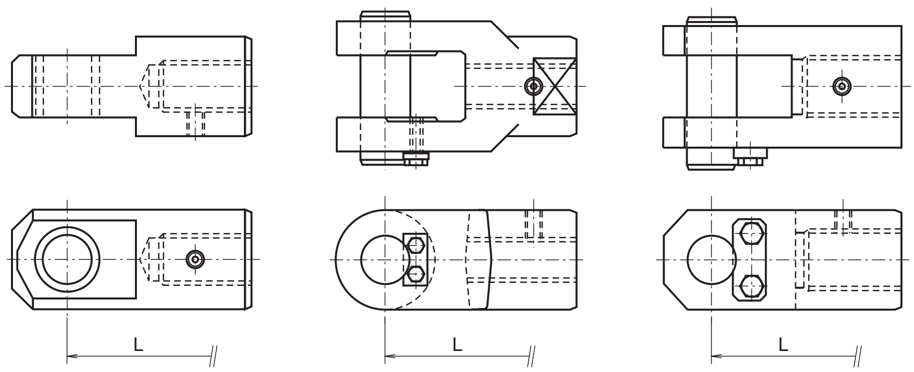


Figure: Example of end bracket

- With proximity switch
  Cylinder with a proximity switch that detects the approach of the piston to a predefined position using a magnetic body embedded in the piston is available. These specifications are used for controlling operation timing by detecting the piston position with a PLC or other control systems.