Air Cylinders' Drive System

Full Stroke Time & Stroke End Velocity

How to Read the Graph

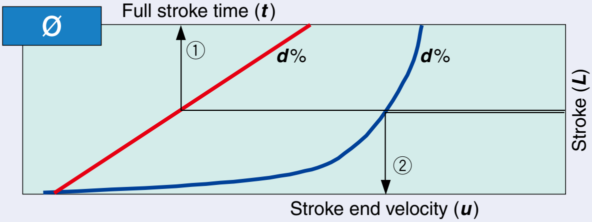
This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment.
As the graph shown below, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

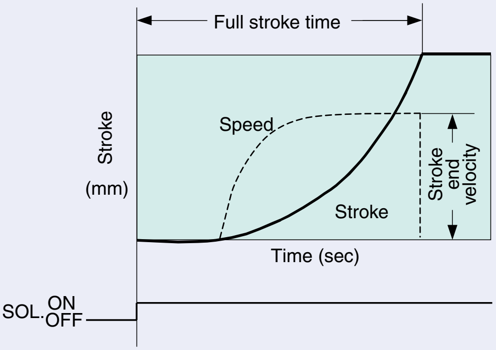
Conditions

Pressure		0.5 MPa
Piping length	**1 m**	CJ2 series, CM2 series, CQ2 series
	2 m	MB series, CQ2 series
	3 m	CS1 series, CS2 series
Cylinder orientation		Vertically upward
Speed controller		Meter-out, connected with cylinder directly, needle fully opened
Load factor		((Load mass x 9.8)/Theoretical output) x 100%

Example

When the cylinder bore size is **ø**, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.





Glossary of Terms: Cylinder's Motion Characteristics

(1) Piston start-up time

It is the time between the solenoid valve is energized (de-energized) and the piston (rod) of a cylinder starts traveling. The accurate judgement is done by the start-up of acceleration curve.

(2) Full stroke time

It is the time between the solenoid valve is energized (de-energized) and the piston (rod) of a cylinder is reached at the stroke end.

(3) 90% force time

It is the time between the solenoid valve is energized (de-energized) and the cylinder output is reached at 90% of the theoretical output.

(4) Mean velocity

Values which divided stroke by "full stroke time". In the sequence or diaphragm, it is used as a substituting expression for "full stroke time".

(5) Max. velocity

It is the maximum values of the piston velocity which occurs during the stroke. In the case of Graph (1), it will be the same values as "stroke end velocity". Like Graph (2), when lurching or stick-slipping occurs, it shows substantially larger values.

(6) Stroke end velocity

It is the piston velocity when the piston (rod) of a cylinder is reached at the stroke end. In the case of a cylinder with adjustable cushion, it says the piston velocity at the cushion entrance. It is used for judging the cushion capability and selecting the buffer mechanism.

(7) Impact velocity

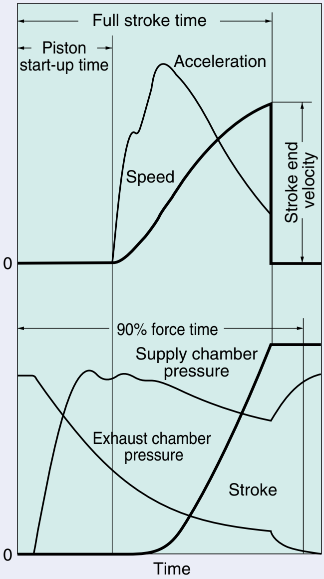
It is the piston velocity when the piston (rod) of a cylinder is collided with the external stopper at the stroke end or arbitrary position.

(Reference)

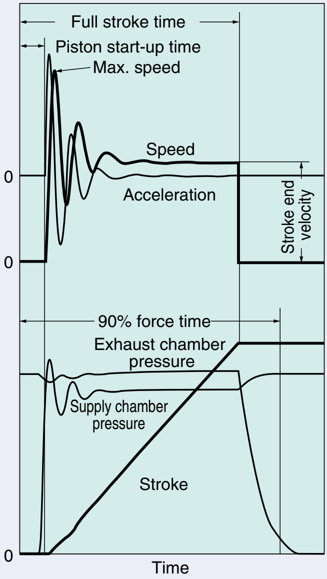
Balancing velocity: If a cylinder having enough longer stroke is driven by meter-out, the latter half of a stroke will be in an uniform motion. Regardless of the supply pressure or a load, the piston speed for this time will be dependent only on the effective area ***S*** [mm^2] of the exhaust circuit and the piston area ***A*** [mm^2] . Balancing velocity = 1.9 x 10^5 x (***S***/***A***) [mm/s] is estimated with this formula.

Note) These definitions are harmonized with SMC "Model Selection Software".

Graph (1)



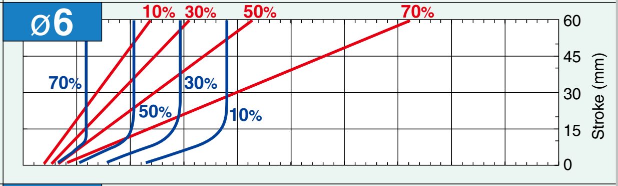
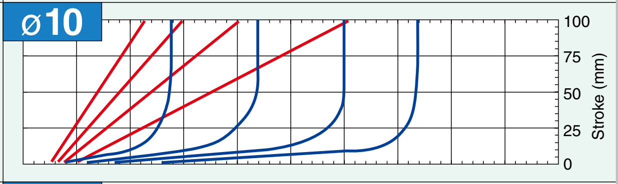
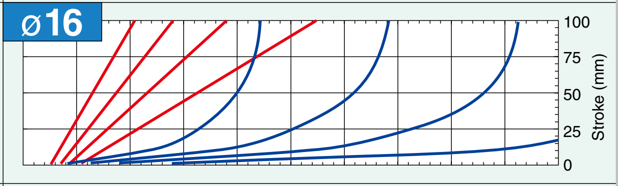
Graph (2)



Air Cylinders’ Drive System

Full Stroke Time & Stroke End Velocity

CJ2 Series/Bore size: ø6, ø10, ø16

Applicable model				Full stroke time (sec)
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	
AN120-M5 AN120-M3	TU0425	**SY3120-M5** **SYJ3120-M3** **VQD1121-M5**	AS1201F-M5-04 AS1200-M5	
AN120-M5	TU0425	**SY3120-M5** **SYJ512□-M5** **VQZ1120-M5**	AS1201F-M5-04 AS1200-M5	
AN120-M5	TU0425	**SY3120-M5** **SYJ512□-M5** **VQZ1120-M5**	AS1201F-M5-04 AS1200-M5	
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	Stroke end velocity (mm/s)
Applicable model				

For details corresponding to each various condition, make the use of “Model Selection Software” on SMC website for your decision.

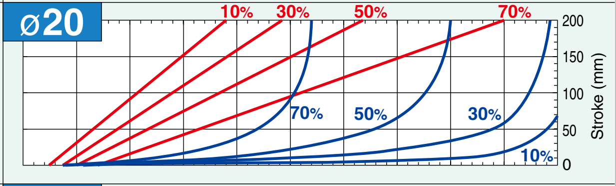
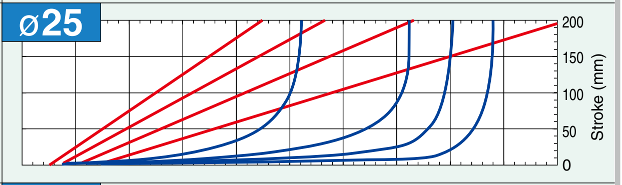
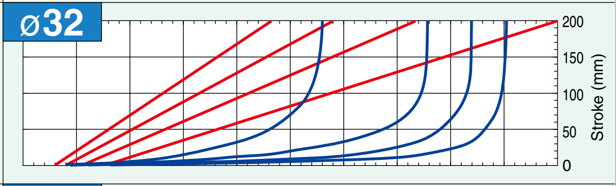
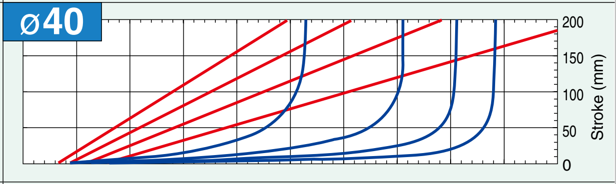
How to Read the Graph

This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment.
As the graph shown at right, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

Conditions

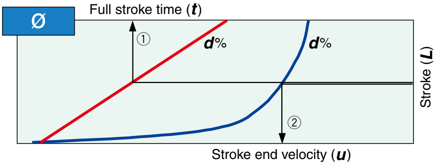
Pressure	0.5 MPa
Piping length	1 m
Cylinder orientation	Vertically upward
Speed controller	Meter-out, connected with cylinder directly, needle fully opened
Load factor	((Load mass x 9.8)/Theoretical output) x 100%

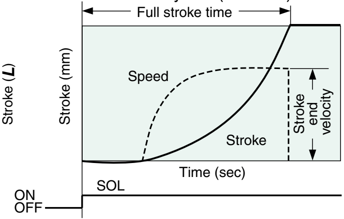
CM2 Series/Bore size: ø20, ø25, ø32, ø40

Applicable model				Full stroke time (sec)
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS2201F-01-04 AS2200-01	
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS2201F-01-04 AS2200-01	
ANB1-01 AN101-01	TU0604	**SY5120-01** **SX5120-01**	AS2201F-01-06 AS2200-01	
ANB1-01 AN101-01	TU0604	**SY5120-01** **SX5120-01**	AS2201F-02-06 AS2200-02	
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	0 100 200 300 400 500 600 700 800 900 1000 Stroke end velocity (mm/s)
Applicable model				

For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

Example When the cylinder bore size is **ø**, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.



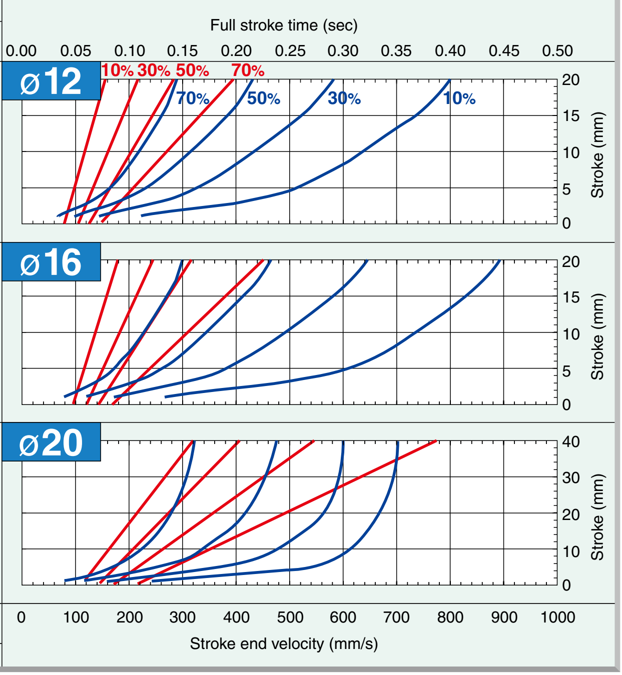


Air Cylinders' Drive System

Full Stroke Time & Stroke End Velocity

CQ2 Series/Bore size: ø12, ø16, ø20

Applicable model			
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS1201F-M5-04 AS1200-M5
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS1201F-M5-04 AS1200-M5
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS1201F-M5-04 AS1200-M5
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
Applicable model			



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

How to Read the Graph

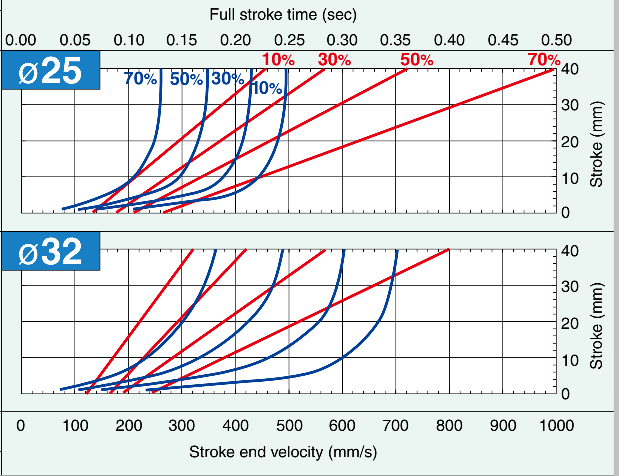
This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment.
As the graph shown at right, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

Conditions

Pressure	0.5 MPa
Piping length	1 m
Cylinder orientation	Vertically upward
Speed controller	Meter-out, connected with cylinder directly, needle fully opened
Load factor	((Load mass x 9.8)/Theoretical output) x 100%

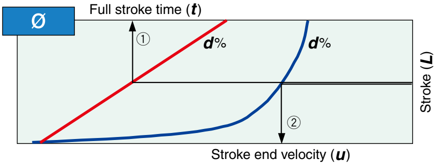
CQ2 Series/Bore size: ø25, ø32

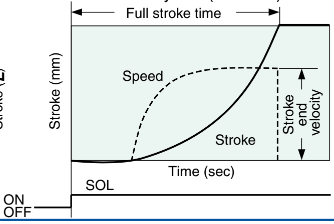
Applicable model			
Silencer	**Tubing**	**Solenoid valve (2 position)**	**Speed controller**
AN120-M5	TU0425	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS1201F-M5-04 AS1200-M5
AN120-M5	TU0604	**SY3120-M5** **SYJ5120-M5** **VQ1160-M5**	AS2201F-01-06 AS2200-01



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

Example When the cylinder bore size is ø, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.



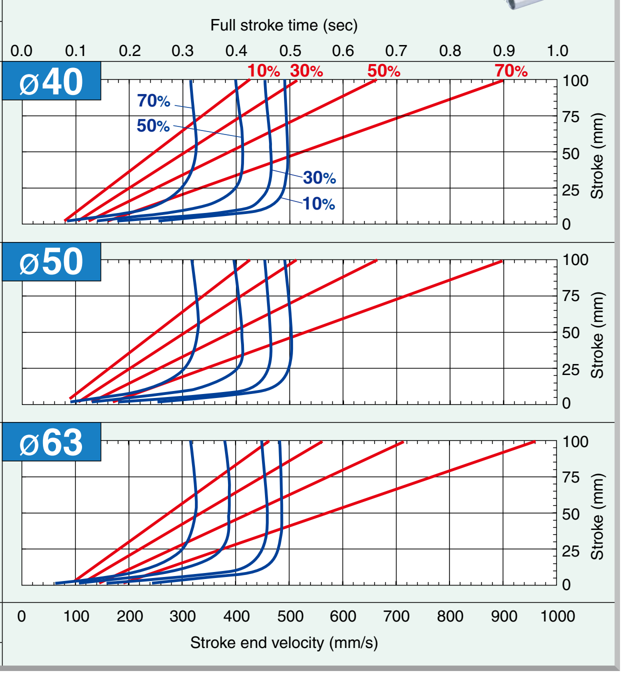


Air Cylinders' Drive System

Full Stroke Time & Stroke End Velocity

CQ2 Series/Bore size: ø40, ø50, ø63

Applicable model			
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
AN101-01	TU0604	**SY5120-01**	AS2201F-01-06 AS2200-01
AN101-01	TU0604	**SY5120-01**	AS2201F-02-06 AS2200-02
AN101-01	TU0805	**SY5120-01**	AS3201F-02-08 AS3000-02
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
Applicable model			



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

How to Read the Graph

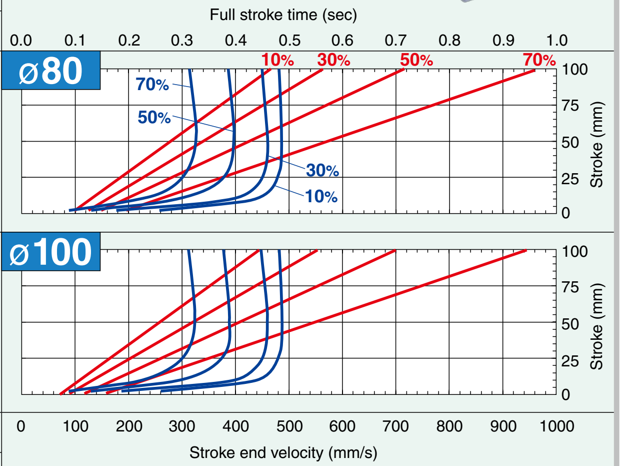
This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment.
As the graph shown at right, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

Conditions

Pressure	0.5 MPa
Piping length	2 m
Cylinder orientation	Vertically upward
Speed controller	Meter-out, connected with cylinder directly, needle fully opened
Load factor	((Load mass x 9.8)/Theoretical output) x 100%

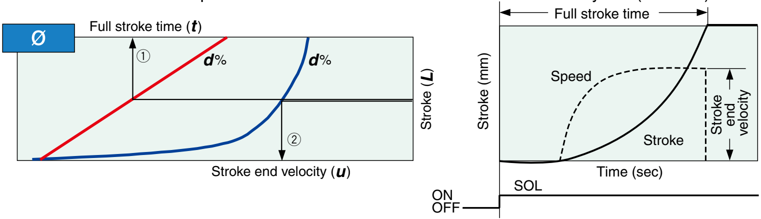
CQ2 Series/Bore size: ø80, ø100

Applicable model				
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	Bore size
AN110-01 AN101-01	TU1065	**SY7120-02** **SX7120-01**	AS4000-03	ø80
ANB1-03 AN30-03	TU1208	**VFS41□□-03** **VFR41□□-03**	AS5000-03 AS420-03	ø100



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

Example When the cylinder bore size is **ø**, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.

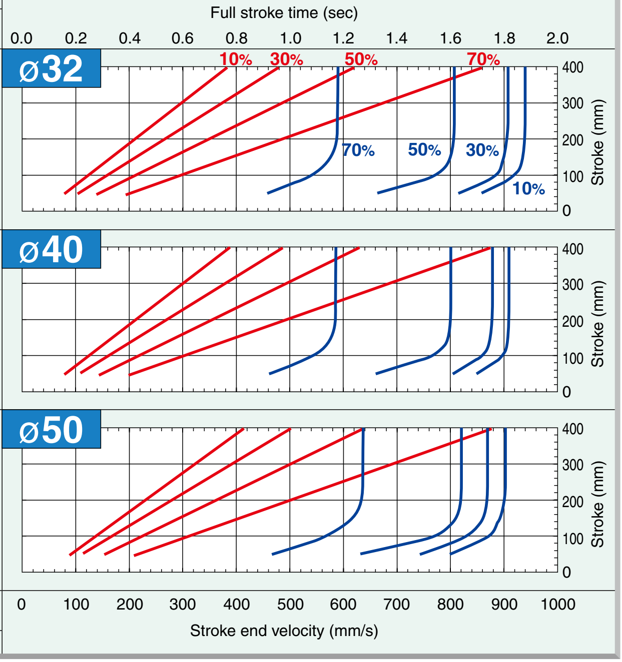


Air Cylinders' Drive System

Full Stroke Time & Stroke End Velocity

MB Series/Bore size ø32, ø40, ø50

Applicable model				
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	Bore size
ANB1-01 AN101-01	TU0604	**SY5120-01** **SX5120-01**	AS2201F-01-06 AS2200-01	ø32
ANB1-01 AN101-01	TU0604	**SY5120-01** **SX5120-01**	AS2201F-02-06 AS2200-02	ø40
ANB1-01 AN101-01	TU0805	**SY5120-01** **SX5120-01**	AS3201F-02-08 AS3000-02	ø50



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

How to Read the Graph

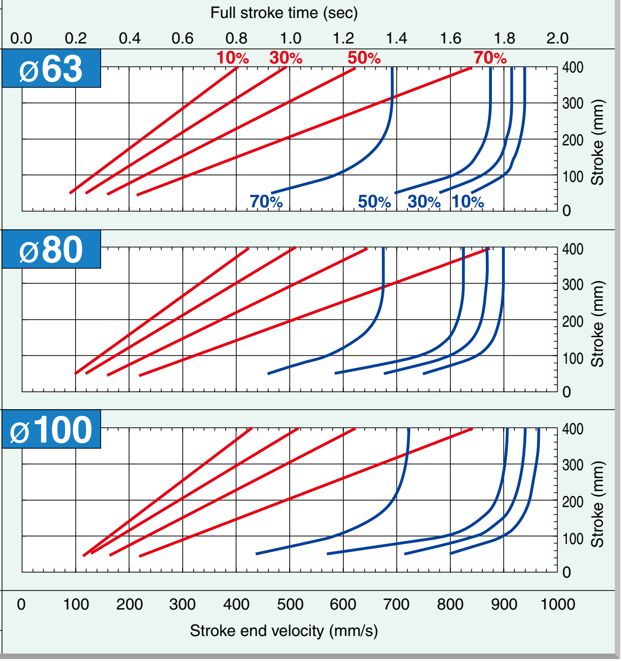
This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment. As the graph shown at right, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

Conditions

Pressure	0.5 MPa
Piping length	2 m
Cylinder orientation	Vertically upward
Speed controller	Meter-out, connected with cylinder directly, needle fully opened
Load factor	((Load mass x 9.8)/Theoretical output) x 100%

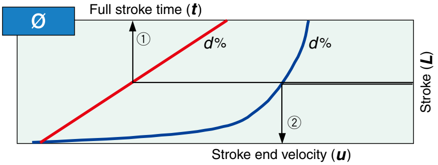
MB Series/Bore size: ø63, ø80, ø100

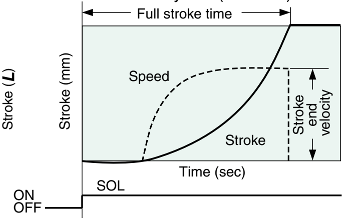
Applicable model			
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
AN110-01 AN101-01	TU1065	**SY7120-02** **SX7120-02**	AS4000-03
ANB1-02 AN20-02	TU1065	**VFS31□□-02** **VFR31□□-02**	AS5000-02 AS420-02
ANB1-03 AN30-03	TU1208	**VFS41□□-03** **VFR41□□-03**	AS5000-03 AS420-03
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller
Applicable model			



For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

Example When the cylinder bore size is **ø**, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.



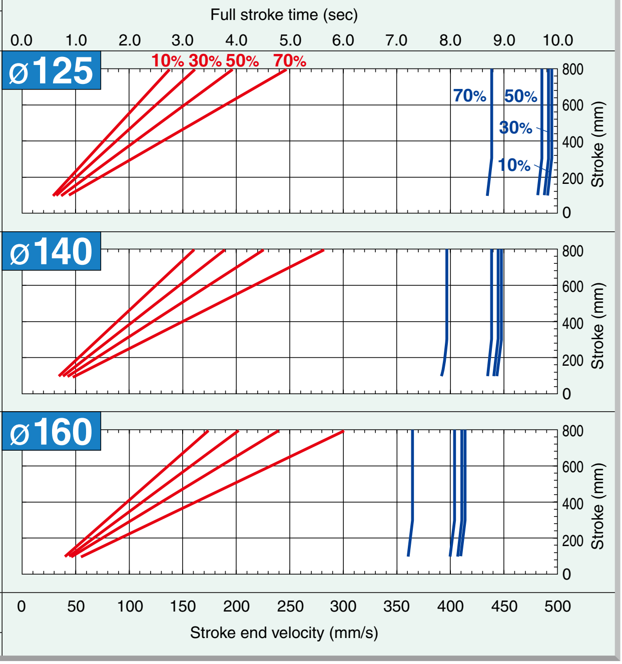


Air Cylinders’ Drive System

Full Stroke Time & Stroke End Velocity

CS1, CS2 Series/Bore size: ø125, ø140, ø160

Applicable model				
Silencer	Tubing	**Solenoid valve (2 position)**	Speed controller	Bore size
ANB1-03 AN30-03	SGP10A	**VFR3100-03** **VEX3320-03**	AS420-02 AS5000-02	ø125
ANB1-03 AN30-03	SGP10A	**VFR3100-03** **VEX3320-03**	AS420-03 AS5000-03	ø140
ANB1-04 AN40-04	SGP10A	**VFR4100-04** **VEX3320-04**	AS420-03	ø160



For details corresponding to each various condition, make the use of “Model Selection Software” on SMC website for your decision.

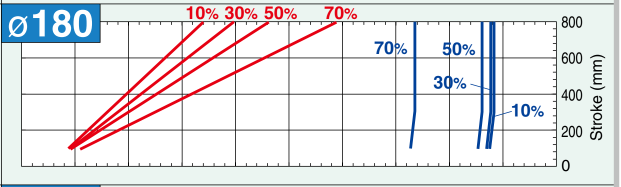
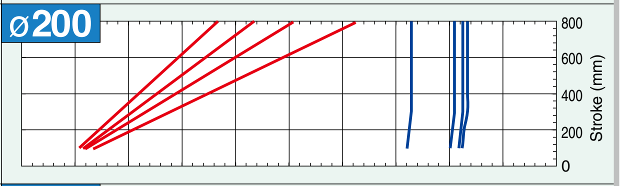
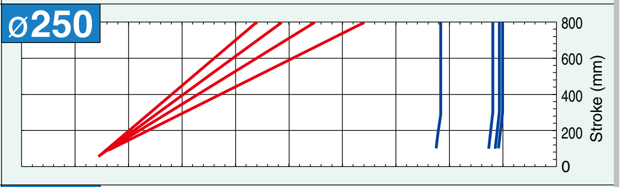
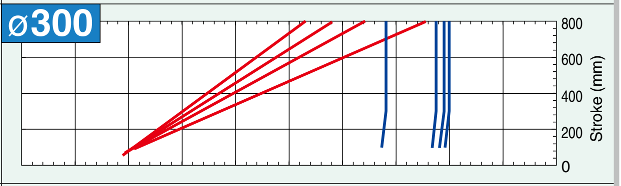
How to Read the Graph

This graph shows the full stroke time and stroke end velocity when a cylinder drive system is composed of the most suitable equipment. As the graph shown at right, various load ratio and full stroke time which corresponds to stroke and terminal velocity are indicated for every cylinder bore size.

Conditions

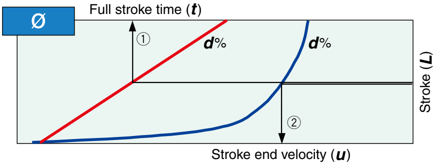
Pressure	0.5 MPa
Piping length	3 m
Cylinder orientation	Vertically upward
Speed controller	Meter-out, connected with cylinder directly, needle fully opened
Load factor	((Load mass x 9.8)/Theoretical output) x 100%

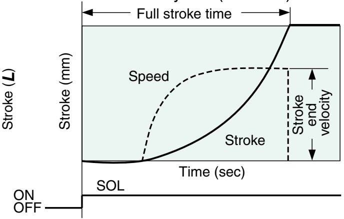
CS1 Series/Bore size: ø180, ø200, ø250, ø300

Applicable model				
Silencer	Tubing	Solenoid valve (2 position)	Speed controller	Full stroke time (sec) 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
ANB1-04 AN40-04	SGP15A	**VEX3500-04** **VP3145-03**	AS420-03	
ANB1-04 AN40-04	SGP15A	**VEX3500-04** **VP3145-03**	AS420-04	
ANB1-06 AN500-06	SGP20A	**VEX3500-06** **VP3145-04**	AS600-10	
ANB1-10 AN600-10	SGP20A	**VEX3500-10** **VP3145-06**	AS600-10	
Silencer	Tubing	Solenoid valve (2 position)	Speed controller	0 50 100 150 200 250 300 350 400 450 500 Stroke end velocity (mm/s)
Applicable model				

For details corresponding to each various condition, make the use of "Model Selection Software" on SMC website for your decision.

Example When the cylinder bore size is ø, its stroke is ***L***, and load ratio is ***d***%, full stroke time ***t*** is obtained, as an arrow mark ①, by reading the value on the abscissa over the point at which the ordinate ***L*** hits the full stroke line (red line) of ***d***%. Terminal velocity ***u*** is obtained, as an arrow mark ②, by reading the value on the abscissa below the point at which the ordinate ***L*** hits the terminal velocity line (blue line) of ***d***%.





Solenoid Valve Flow Rate Characteristics

(How to indicate flow rate characteristics)

1. Indication of flow rate characteristics

The flow rate characteristics in equipment such as a solenoid valve, etc. are indicated in their specifications as shown in Table (1).

Table (1) Indication of Flow Rate Characteristics

Corresponding equipment	Indication by international standard	Other indications	Conformed standard
Pneumatic equipment	C, b	—	**ISO 6358: 1989** **JIS B 8390: 2000**
	—	S	**JIS B 8390: 2000** **Equipment: JIS B 8379, 8381-1, 8381-2**
		Cv	**ANSI/(NFPA)T3.21.3 R1-2008**
Process fluid control equipment	Kv	—	**IEC60534-1: 2005** **IEC60534-2-3: 1997** **JIS B 2005-1: 2012** **JIS B 2005-2-3: 2004** **Equipment: JIS B 8471, 8472, 8473**
	—	Cv	

2. Pneumatic equipment

2.1 Indication according to the international standards

(1) Conformed standard

ISO 6358: 1989 : Pneumatic fluid power—Components using compressible fluids—Determination of flow rate characteristics

JIS B 8390: 2000 : Pneumatic fluid power—Components using compressible fluids—How to test flow rate characteristics

(2) Definition of flow rate characteristics

The flow rate characteristics are indicated as a result of a comparison between sonic conductance C and critical pressure ratio b.

Sonic conductance C : Value which divides the passing mass flow rate of an equipment in a choked flow condition by the product of the upstream absolute pressure and the density in a standard condition.

Critical pressure ratio b : Pressure ratio (downstream pressure/upstream pressure) which will turn to a choked flow when the value is smaller than this ratio.

Choked flow : The flow in which the upstream pressure is higher than the downstream pressure and where sonic speed in a certain part of an equipment is reached. Gaseous mass flow rate is in proportion to the upstream pressure and not dependent on the downstream pressure.

Subsonic flow : Flow greater than the critical pressure ratio

Standard condition : Air in a temperature state of 20°C, absolute pressure 0.1 MPa (= 100 kPa = 1 bar), relative humidity 65%. It is stipulated by adding the “(ANR)” after the unit depicting air volume. (standard reference atmosphere) Conformed standard: ISO 8778: 1990 Pneumatic fluid power—Standard reference atmosphere, JIS B 8393: 2000: Pneumatic fluid power—Standard reference atmosphere

(3) Formula for flow rate

It is described by the practical units as following.

When

$$\frac{P_2 + 0.1}{P_1 + 0.1} \leq b\text{, choked flow}$$

$$Q = 600 \times C\,(P_1 + 0.1)\sqrt{\frac{293}{273 + T}} \quad \cdots\cdots(1)$$

When

$$\frac{P_2 + 0.1}{P_1 + 0.1} > b\text{, subsonic flow}$$

$$\boldsymbol{Q} = 600 \text{ x } \boldsymbol{C}\,(\boldsymbol{P_1} + 0.1)\sqrt{1 - \left[\frac{\dfrac{\boldsymbol{P_2} + 0.1}{\boldsymbol{P_1} + 0.1} - \boldsymbol{b}}{1 - \boldsymbol{b}}\right]^2}\sqrt{\frac{293}{273 + \boldsymbol{T}}} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$\boldsymbol{Q}$: Air flow rate [L/min (ANR)]
$\boldsymbol{C}$: Sonic conductance [dm^3/(s·bar)], dm^3 (Cubic decimeter) of SI = L (liter).
$\boldsymbol{b}$: Critical pressure ratio [—]
$\boldsymbol{P_1}$: Upstream pressure [MPa]
$\boldsymbol{P_2}$: Downstream pressure [MPa]
$\boldsymbol{T}$: Temperature [°C]

Note) Formula of subsonic flow is the elliptic analogous curve.

Flow rate characteristics are shown in Graph (1). For details, please use the calculation software available from SMC website.

Example)

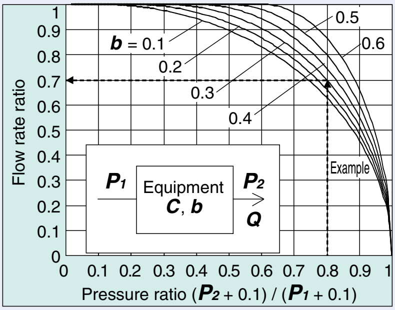
Obtain the air flow rate for $\boldsymbol{P_1}$ = 0.4 [MPa], $\boldsymbol{P_2}$ = 0.3 [MPa], $\boldsymbol{T}$ = 20 [°C] when a solenoid valve is performed in $\boldsymbol{C}$ = 2 [dm^3/(s·bar)] and $\boldsymbol{b}$ = 0.3.

According to formula 1, the maximum flow rate = $600 \text{ x } 2 \text{ x } (0.4 + 0.1) \text{ x} \sqrt{\dfrac{293}{273 + 20}} = 600$ [L/min (ANR)]

Pressure ratio = $\dfrac{0.3 + 0.1}{0.4 + 0.1} = 0.8$

Based on Graph (1), it is going to be 0.7 if it is read by the pressure ratio as 0.8 and the flow ratio to be $\boldsymbol{b}$ = 0.3.

Hence, flow rate = Max. flow x flow ratio = 600 x 0.7 = 420 [L/min (ANR)]



Graph (1) Flow rate characteristics

Solenoid Valve Flow Rate Characteristics

(How to indicate flow rate characteristics)

2.1 Indication according to the international standards

(4) Test method

Attach a test equipment with the test circuit shown in Fig. (1) while maintaining the upstream pressure to a certain level which does not go below 0.3 MPa. Next, measure the maximum flow to be saturated in the first place, then measure this flow rate at 80%, 60%, 40%, 20% and the upstream and downstream pressure. And then, obtain the sonic conductance ***C*** from this maximum flow rate. In addition, calculate ***b*** using each data of others and the subsonic flow formula, and then obtain the critical pressure ratio ***b*** from that average.

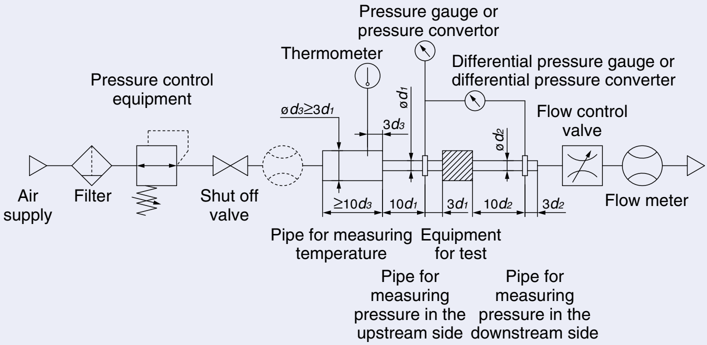


Fig. (1) Test circuit based on ISO 6358: 1989, JIS B 8390: 2000

2.2 Effective area *S*

(1) Conformed standard

JIS B 8390: 2000: Pneumatic fluid power—Components using compressible fluids—Determination of flow rate characteristics

Equipment standards: **JIS B 8373: Solenoid valve for pneumatics**
JIS B 8379: Silencer for pneumatics
JIS B 8381-1: Fittings for pneumatics—Part 1: Push-in fittings for thermoplastic resin tubing
JIS B 8381-2: Fittings for pneumatics—Part 2: Compression fittings for thermoplastic resin tubing

(2) Definition of flow rate characteristics

Effective area ***S***: The cross-sectional area having an ideal throttle without friction deduced from the calculation of the pressure changes inside an air tank or without reduced flow when discharging the compressed air in a choked flow, from an equipment attached to the air tank. This is the same concept representing the “easy to run through” as sonic conductance ***C***.

(3) Formula for flow rate

When

$\frac{P_2 + 0.1}{P_1 + 0.1} \leq 0.5$, **choked flow**

$$Q = 120 \times S\,(P_1 + 0.1)\sqrt{\frac{293}{273 + T}} \quad \cdots\cdots (3)$$

When

$\frac{P_2 + 0.1}{P_1 + 0.1} > 0.5$, **subsonic flow**

$$Q = 240 \times S\,\sqrt{(P_2 + 0.1)\,(P_1 - P_2)}\sqrt{\frac{293}{273 + T}} \quad \cdots\cdots (4)$$

Conversion with sonic conductance ***C***:

$$S = 5.0 \times C \quad \cdots\cdots (5)$$

Q : Air flow rate[L/min(ANR)]
S : Effective area [mm^2]
P_1 : Upstream pressure [MPa]
P_2 : Downstream pressure [MPa]
T : Temperature [°C]

Note) Formula for subsonic flow (4) is only applicable when the critical pressure ratio b is the unknown equipment. In the formula (2) by the sonic conductance C, it is the same formula as when $b = 0.5$.

(4) Test method

Attach a test equipment with the test circuit shown in Fig. (2) in order to discharge air into the atmosphere until the pressure inside the air tank goes down to 0.25 MPa (0.2 MPa) from an air tank filled with the compressed air at a certain pressure level (0.5 MPa) which does not go below 0.6 MPa. At this time, measure the discharging time and the residual pressure inside the air tank which had been left until it turned to be the normal values to determine the effective area S, using the following formula. The volume of an air tank should be selected within the specified range by corresponding to the effective area of an equipment for test. In the case of JIS B 8379, the pressure values are in parentheses and the coefficient of the formula is 12.9.

$$S = 12.1 \frac{V}{t} \log_{10} \left(\frac{Ps + 0.1}{P + 0.1} \right) \sqrt{\frac{293}{T}} \cdots\cdots\cdots\cdots\cdots\cdots (6)$$

S : Effective area [mm^2]
V : Air tank capacity [L]
t : Discharging time [s]
Ps : Pressure inside air tank before discharging [MPa]
P : Residual pressure inside air tank after discharging [MPa]
T : Temperature inside air tank before discharging [K]

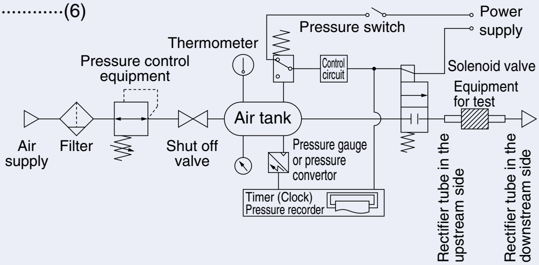


Fig. (2) Test circuit based on JIS B 8390: 2000

2.3 Flow coefficient Cv factor

The United States Standard ANSI/(NFPA)T3.21.3: R1-2008R: Pneumatic fluid power—Flow rating test procedure and reporting method for fixed orifice components

This standard defines the Cv factor of the flow coefficient by the following formula that is based on the test conducted by the test circuit analogous to ISO 6358.

$$Cv = \frac{Q}{114.5 \sqrt{\frac{\Delta P (P_2 + P_a)}{T_1}}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (7)$$

ΔP : Pressure drop between the static pressure tapping ports [bar]
P_1 : Pressure of the upstream tapping port [bar gauge]
P_2 : Pressure of the downstream tapping port [bar gauge]: $P_2 = P_1 - \Delta P$
Q : Flow rate [L/s standard condition]
Pa : Atmospheric pressure [bar absolute]
T_1 : Upstream absolute temperature [K]

Test conditions are $P_1 + Pa = 6.5 \pm 0.2$ bar absolute, $T_1 = 297 \pm 5$K, $0.07 \text{ bar} \leq \Delta P \leq 0.14$ bar.

This is the same concept as effective area A which ISO 6358 stipulates as being applicable only when the pressure drop is smaller than the upstream pressure and the compression of air does not become a problem.

Solenoid Valve Flow Rate Characteristics

(How to indicate flow rate characteristics)

3. Process fluid control equipment

(1) Conformed standard

IEC60534-1: 2005: Industrial-process control valves. Part 1: control valve terminology and general considerations
IEC60534-2-3: 1997: Industrial-process control valves. Part 2: Flow capacity, Section Three- Test procedures
JIS B 2005-1: 2012: Industrial-process control valves – Part 1: Control valve terminology and general considerations
JIS B 2005-2-3: 2004: Industrial-process control valves – Part 2: Flow capacity – Section 3: Test procedures
Equipment standards: JIS B 8471: Solenoid valve for water
JIS B 8472: Solenoid valve for steam
JIS B 8473: Solenoid valve for fuel oil

(2) Definition of flow rate characteristics

Kv factor: Value of the clean water flow rate represented by m^3/h that runs through the valve (equipment for test) at 5 to 40°C, when the pressure difference is 1×10^5 Pa (1 bar). It is calculated using the following formula:

$$Kv = Q\sqrt{\frac{1 \times 10^5}{\Delta P} \cdot \frac{\rho}{1000}} \quad \cdots\cdots (8)$$

Kv : Flow coefficient [m^3/h]
Q : Flow rate [m^3/h]
ΔP : Pressure difference [Pa]
ρ : Density of fluid [kg/m^3]

(3) Formula of flow rate

It is described by the practical units. Also, the flow rate characteristics are shown in Graph (2).

In the case of liquid:

$$Q = 53Kv\sqrt{\frac{\Delta P}{G}} \quad \cdots\cdots (9)$$

Q : Flow rate [L/min]
Kv : Flow coefficient [m^3/h]
ΔP : Pressure difference [MPa]
G : Relative density [water = 1]

In the case of saturated aqueous vapor:

$$Q = 232Kv\sqrt{\Delta P(P_2 + 0.1)} \quad \cdots\cdots (10)$$

Q : Flow rate [kg/h]
Kv : Flow coefficient [m^3/h]
ΔP : Pressure difference [MPa]
P_1 : Upstream pressure [MPa]: $\Delta P = P_1 - P_2$
P_2 : Downstream pressure [MPa]

Conversion of flow coefficient:

$$Kv = 0.865\,Cv \quad \cdots\cdots (11)$$

Here,

Cv factor: Value of the clean water flow rate represented by US gal/min that runs through the valve at 40 to 100°F, when the pressure difference is 1 lbf/in^2 (psi)

Value is different from ***Kv*** and ***Cv*** factors for pneumatic purpose due to different test method.

(4) Test method

Connect the equipment for the test to the test circuit shown in Fig. (3), and run water at 5 to 40°C. Then, measure the flow rate with a pressure difference where vaporization does not occur in a turbulent flow (pressure difference of 0.035 MPa to 0.075 MPa when the inlet pressure is within 0.15 MPa to 0.6 MPa). However, as the turbulent flow is definitely caused, the pressure difference needs to be set with a large enough difference so that the Reynolds number does not fall below 1 x 10^5, and the inlet pressure needs to be set slightly higher to prevent vaporization of the liquid. Substitute the measurement results in formula (8) to calculate $\boldsymbol{Kv}$.

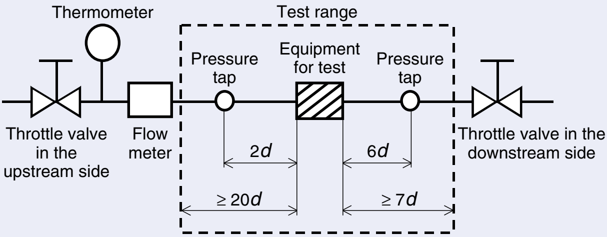
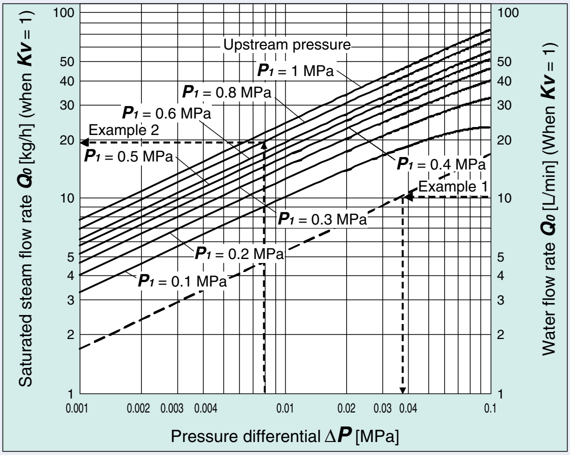


Fig. (3) Test circuit based on IEC60534-2-3, JIS B 2005-2-3



Graph (2) Flow rate characteristics

Example 1)

Obtain the pressure difference when water [15 L/min] runs through the solenoid valve with a $\boldsymbol{Kv}$ = 1.5 m^3/h. As the flow rate when $\boldsymbol{Kv}$ = 1 is calculated as the formula: $\boldsymbol{Q_0}$ = 15 x 1/1.5 = 10 [L/min], read off $\Delta \boldsymbol{P}$ when $\boldsymbol{Q_0}$ is 10 [L/min] in Graph (2). The reading is 0.036 [MPa].

Example 2)

Obtain the saturated steam flow rate when $\boldsymbol{P_1}$ = 0.8 [MPa] and $\Delta \boldsymbol{P}$ = 0.008 [MPa] with a solenoid valve with a $\boldsymbol{Kv}$ = 0.05 [m^3/h]. Read off $\boldsymbol{Q_0}$ when $\boldsymbol{P_1}$ is 0.8 and $\Delta \boldsymbol{P}$ is 0.008 in Graph (2), the reading is 20 kg/h. Therefore, the flow rate is calculated as the formula: $\boldsymbol{Q}$ = 0.05/1 x 20 = 1 [kg/h].