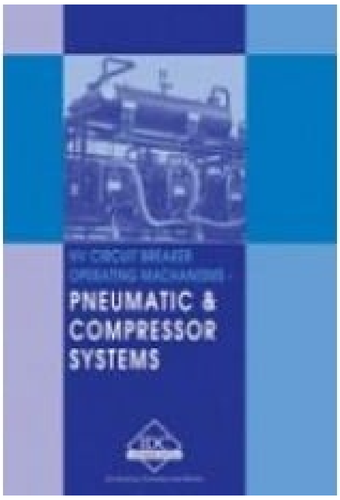
HP-E - HV Circuit Breaker Operating Mechanisms - Pneumatic & Compressor Systems



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Short Description

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Basic pneumatics for circuit breakers

1.1 What is pneumatics?

Pneumatics is the transmission and control of power, using gas as the fluid medium.

Power in a machine can be transmitted to the different parts of the machine by using electricity, mechanical connections, pneumatics or hydraulics. Generally a combination of the methods is used for power transmission. Fluids are used widely for transmission all over the world.

Fluid

A fluid is any material capable of flowing and it is usually a liquid or a gas.

Fluid power

Fluid power is the transmission and control of power using flowing fluids, under pressure, as the transmitting medium in a closed or restricted system.

1.1.1 Examples of uses of fluid power

Field	Application
Electricity Supply	Circuit Breakers
Manufacturing	Handling, Bundling, Tying, Presses, Machine Tools, Mixing, Lifting
Mining	Continuous miners, Pit props, Drills

Agriculture Farm Equipment

Aircraft Undercarriage, Flight controls, Cargo ramps, De-icing of wings

Marine Steering, Stabilizers, Winches, Cargo doors

Forestry Earth moving equipment, Tree loppers, Tree strippers

Transport Automatic doors of trains, Brakes and Lifting equipment

Entertainment Amusement park rides

Pneumatics has the following advantages over other means of power transmission.

- The equipment is light
- System does not require return lines for the used fluid
- Infinite control of speed and pressure
- Pneumatic systems are faster and high speeds can be achieved
- Instant reaction to change of direction, including stopping and starting
- Large forces can be easily transmitted
- The pipe lines can be relatively easily installed and can be run at any angle
- Pneumatic transmission is cheaper, as air costs nothing
- Storage facilities are not required for air till it is in compressed form
- The system is relatively compact for the forces transmitted and it is easy to make the system flexible

- Environmental impact is very less
- It is safe to use in explosion risk areas
- Very little effect due to temperature variations up to 120°C

Pneumatic fluid

The common pneumatic fluid used is air. Inert gases like nitrogen are used in special applications to reduce the risk of fire or explosion

Composition of air

Air contains a mixture of gases and other particles. The main constituents are nitrogen and oxygen. Air is made up of approximately 78% nitrogen, 20% oxygen and 2% of other gases.

Figure 1.1

Composition of air

Properties of air

Air is like any other fluid; it fills up the container it occupies. The desirable property of air is that, it is cheap and that it is compressible and can be made to perform a number of operations. The drawbacks of air are that it contains moisture and does not have the ability to lubricate moving parts.

1.2 Units of measurement

All the measurements in this manual are based on the standard base units of 'Length', 'Mass' and 'Time'. S.I system (Systéme International) is the system of measurement used in Australia. It is based on the Metric system and makes use of the decimal system.

Base units

The base units of measurement are as follows

Quantity	Unit of measurement	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s

Table 1.1

Basic units of measurement

Measurements which are made up from combinations of base units are called derived units.

The following are derived units

- Force
- Area
- Volume
- Pressure

Force

Definition of ‘Force’ as applied to pneumatics is ‘Any cause that tends to produce or modify motion’.

Force = mass × acceleration

= m a

Force is measured in Newtons. One Newton (N) is the force required to accelerate a mass of one kilogram at a rate of one meter per second per second.

Newton = kilogram × meters per second per second

$N = kg \times m/s^2$

Acceleration due to gravity is commonly used for calculations and it is equal to 9.81 m/s^2.

Area

Area is the measure of the size of a surface. Area is measured in meters squared – m^2

Area of a rectangle $A = l \times b$ where l and b are the length and breadth of the rectangle

Area of a circle $A = \frac{? \times \text{diameter} \times \text{diameter}}{4}$

$$A = \frac{? D^2}{4}$$

Volume

Volume of a container is a measure of how much fluid it can accommodate inside it. The unit of measurement is cubic metre (m^3)

Volume = Area × Length

$$V = A \times l$$

Pressure

Pressure is the result of application of force on an area. The unit of pressure is Pascal. One Pascal is the pressure resulting from the application of 1 Newton force on an area of 1 square meter.

$$\text{Pressure (P)} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} = \frac{N}{m^2}$$

Figure 1.2

Relation between Force, Pressure and Area

Pressure is expressed in three different ways

- Atmospheric pressure
- Gauge pressure – both positive and negative (vacuum) pressure
- Absolute pressure

Atmospheric pressure

Atmospheric pressure is the pressure exerted by the air around us. The pressure varies with the altitude. At sea level, the atmospheric pressure is approximately equal to 101.3 kilopascal. It is the force exerted by a column of air directly above an area of one square meter.

The atmospheric pressure at sea level is approximately equal to 760 mm of a mercury column. Refer to Figure 1.3 which shows that the atmospheric pressure is holding a 760 mm column of mercury inside the glass tube. The atmospheric pressure drops with elevation.

Figure 1.3

Atmospheric pressure

Gauge pressure

Gauge pressure is the reading obtained from a pressure gauge. Gauges can be calibrated to indicate any pressure required.

Absolute pressure

Absolute pressure is the total pressure obtained by the addition of gauge pressure and atmospheric pressure.

Prefixes

Prefix is a syllable or syllables which is placed at the beginning of a unit or word to indicate a multiple or submultiples of a unit

In S.I. system, the commonly used prefixes in pneumatics are

- Mega
- kilo
- Centi
- milli
- micro

PREFIX	VALUE	SYMBOL
Mega	10^{6}	M
kilo	10^{3}	k
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	?

Table 1.2

Prefixes used with the units in pneumatic system

The unit ‘Pascal’ is very small and hence, it is mostly used with a prefix. Pressures of 10 000 000 Pa are used quite often. Using prefixes, the same pressure can be mentioned in various ways like following

10 000 000 Pa

= 10 000 kPa (10 000 kilopascals)

= 10 MPa (10 Megapascals)

Another unit used commonly to denote pressure is ‘Bar’, even though it is not an Australian Standard unit. One ‘Bar’ is approximately equal to 100 kPa or 0.1 MPa.

10 000 kPa = 100 Bar

Temperature

Temperature is measured in degrees Centigrade or Celcius ($?^C$). Absolute temperatures are used for the calculation of temperatures encountered during compression of air. The unit of absolute temperature is Kelvin (K).

Absolute zero on the Kelvin temperature scale equals –273$?^C$.

One $?^C$ is equal to 1 Kelvin unit and so to convert $?^C$ to Kelvin, 273 is added to the centigrade temperature. To convert Kelvin to Centigrade, subtract 273 from the Kelvin units.

–100$?^C$ = 173 K

0?^{C} = 273 K

100?^{C} = 373 K

1.3 Pascal’s law

Pascal's law states that "Pressure applied to a confined static fluid is transmitted equally and undiminished in all directions throughout that fluid and acts with equal force on equal areas".

Figure 1.4

Pascal's Law

1.4 Force multiplication

The force acting on the piston in a large cylinder is greater than the force on the piston in a smaller cylinder for the same pressure due to the relationship formula shown below.

Force = Pressure × Area

For the same pressure, if the cross sectional area of the cylinder is doubled, then the force is also doubled. This principle is used in pneumatic systems where, much larger forces can be generated on a bigger sized piston by using the same pressure developed by a smaller sized piston.

Figure 1.5

Force amplification

For the smaller piston

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$= \frac{50}{20} = 2.5$$

The same pressure gets transmitted to the bigger piston. The force acting on the bigger piston is given by

$$\text{Force} = \text{Pressure} \times \text{Area}$$

$$= 2.5 \times 400$$

$$= 1000 \text{ Newtons}$$

The force is observed to have been amplified by the same proportion as the increase in the piston area. This principle is used in pneumatics to obtain much higher forces from lower values of applied forces.

1.5 Pressure intensification

Pressure intensification is used where a large pressure increase is required in a portion of the system. By using pressure intensifier it is possible to generate much higher forces, than what the pressure source is capable of developing. The Figure 1.6 shows the construction of a pressure intensifier.

Figure1.6

Construction of a pressure intensifier

Pressure intensifiers use two pistons having different areas and mechanically connected to each other. The inlet and outlet ports are connected to virtually separate systems.

When pressure is applied to the inlet port, the force on the bigger piston is directly transmitted to the smaller piston by the mechanical connection. The smaller piston then transmits the force to the fluid in the outlet port. Since the force is applied to a smaller area of the piston, the pressure is increased in direct proportion to the increase in the utilized area of the piston.

Figure1.7

Principle of operation of a pressure intensifier

For the large piston section

$$\text{Force} = \text{Pressure} \times \text{Area}$$

$$= 900000 \times 0.001256$$

$$= 1130.9 \text{ Newtons}$$

For the small piston section

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$= \frac{1130.97}{0.000078}$$

$$= 14\ 400\ 000 \text{ Pa}$$

$$= 14.4 \text{ MPa}$$

In the above example of pressure intensifier, the pressure has been intensified from 900 kPa to 14.4 MPa.

1.6 Pressure acting on different areas

Application of same force on different piston areas produces different forces and this phenomenon is used effectively in some pneumatic systems. Refer to Figure 1.8.

Figure 1.8

Pressure on different sized pistons

When compressed air is introduced in the space between the two pistons, the forces developed on the two pistons are different due to the difference in the piston areas. In the calculation of the forces acting on pistons, the area of the shaft must be subtracted from the total area of the piston. The subtracted net area of the piston is called the annular area as shown in the Figure 1.9.

Figure 1.9

Annular area

The calculation of the forces acting on the two pistons can be calculated for the following case. Refer to Figure 1.10.

Figure 1.10

Forces on pistons having different areas

Large Piston,

Annular area of the piston $= \frac{?D^2}{4} - \frac{?d^2}{4}$

$= \frac{? \times 0.04^2}{4} - \frac{? \times 0.01^2}{5}$

$= \frac{? \times (0.04^2 - 0.01^2)}{4}$

$$= 1.17809 \times 10^{-3}$$

Small Piston

Annulus area of the piston $= \frac{?D^2}{4} - \frac{?d^2}{4}$

$$= \frac{? \times 0.02^2}{4} - \frac{? \times 0.01^2}{4}$$

$$= \frac{? \times (0.02^2 - 0.01^2)}{4}$$

$$= 2.35619 \times 10^{--4}$$

The force acting on the large piston is

$$F = p \times A$$

$$= 3\,000\,000 \times 0{,}00117809$$

$= 3\ 534.2917$ Newtons

$= 3.53$ kN

The force acting on the small piston is

$F = p \times A$

$= 3\ 000\ 000 \times 0.000235619$

$= 706.85835$ Newtons

$= 0.71$ Kn

The difference between the forces acting on the two pistons is

$= 3.53 - 0.71$

$= 2.82$ kN

Since the force acting on the large piston is more than the force acting on the smaller piston the piston will move towards left.

Figure 1.11 is an application of a pneumatic system with a piston, cylinder assembly.

Figure 1.11

Double acting linear actuator

The force on the piston from the side of Port 1 is more than the force acting on the piston from Port 2 side for the same pressure. This is due to the reduced area of the piston on account of the shaft connection.

1.7 Gas laws

Gas laws explain the behaviour of the gas when the pressure and temperature of the gas changes.

There are several laws and a few of them are given below.

Boyle's law

When the temperature of an enclosed gas is kept constant, and the pressure is increased, the volume of the gas is decreased by the same proportion. The formula for Boyle's law is

$$P_1 \times V_1 = P_2 \times V_2$$

Absolute pressures have to be used while using the above formula.

Charles law

At constant pressure, the volume of gas varies in direct proportion to a change in temperature. The formula for Charles law is

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Absolute temperatures have to be used while using the above formula

Gay-Lussac’s law

At constant volume, the pressure in a confined gas chamber is directly proportional to the absolute temperature of the gas.

The formula for Gay-Lussac’s Law is

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Absolute temperatures have to be used while using the above formula

Combined gas law

The combined law is a combination of the gas laws of Boyle, Charles and Gay-Lussac.

The formula for the Combined Gas Law is

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

Absolute temperatures and pressures have to be used while using the above formula.

Using this formula, it is possible to calculate the value of one unknown, if the values of the other five parameters are known. The gauge pressures have to be converted to absolute pressures and the temperatures in degrees centigrade have to be converted to Kelvin units.

Example

Calculation of final temperature of 5 m^3 of air at atmospheric pressure and a temperature of 20?C, when it is compressed into a 1 m^3 volume at a gauge pressure of 500 kPa.

$$\frac{P_1 X V_1}{T_1} = \frac{P_2 X V_2}{T_2}$$

where P_1 = 101.3 kPa (absolute)

V_1 = 5 m^3

T_1 = 20 ?C + 273 = 293 K (absolute)

P2 = 500 kPa + 101.3 (absolute)

= 601.3 kPa

V2 = 1 m3

$$\text{Therefore} \quad T_2 = \frac{P_2 \times V_2 \times T_1}{P_1 \times V_1}$$

$= (601.3 \times 1 \times 293) \div (101.3 \times 5)$

$= 347.8$ K (absolute)

= 74.8?C

1.8 Pneumatic symbols

In a pneumatic circuit, the various pneumatic components are shown in the form of symbols.

Table 1.3 shows the pneumatic symbols and their description.

Symbol	**Description**
	Pressure Line

Exhaust Line, Control Line

Enclosing Line

Mechanical Connection

Vacuum Pump

Lines Crossing

Lines Connected

Fixed Restriction

Variable Restriction

Fluid Flow Direction

Pressure Gauge

Pneumatic Compressor

Linear Actuator

Basic Envelope - Filters and Lubricators

Filter - Manual Drain

Filter Automatic Drain

Lubricator (Less Drain)

Lubricator (Manual Drain)

Air Dryer

Pressure Regulator - Adjustable Self Relieving

Pressure Regulator - Adjustable Non Relieving

Accumulator

Check Valve

Valve - One Flow Path

Valve Two Flow Paths

Valve - Two Closed Ports

Plugged line

Shuttle Valve

Silencer

Cylinder Spring Return

Pressure Actuated Electric Switch

Shutoff Valve

Flow Gauge

Check Valve

Check Valve - Spring Loaded

Solenoid

Cylinder Double Acting

Table 1.3

Pneumatic circuit symbols

Table 1.4 below gives the conversion of the measurement units

Conversion Table

From	To	Multiply by

Inches	mm	25.4
Feet	Metres	0.3048
Square Feet	Square Metres	0.09290
Cubic Feet	Cubic Metres	0.02832
Pounds	kgs	0.4536
PSI ($lb/inch^2$)	Bar	0.06895

Table 1.4

Conversion table for units of measurement

1.9 Safety with pneumatics

Figure 1.12

Hazards of compressed air

Precautions when using compressed air

- Take care while using compressed air for cleaning because flying particles may cause injury
- Loose and unrestrained hoses can whip around when compressed air flows through them
- Don’t direct compressed air at the body, as compressed air can enter into the blood stream
- Ensure that the exhaust air from pneumatic equipment does not blow dust and dirt around the work place

- Put danger tags on the controls and other prominent places on equipment that is being worked upon
- Depressurize the system before you start to work on it
- Doubly ensure that there is no trapped pressure in a system before undoing a joint or inspecting a crack
- Do not work under loads that are stuck up in the air