

# Nature and causes of fault in power system

Any fault in electrical apparatus is nothing but the defect in its electrical circuit which makes current path directed from its intended path. Normally due to breaking of conductors or failure of insulation, these faults occur. The other reasons for occurrence of fault include mechanical failure, accidents, excessive internal and external stresses. The impedance of the path in the fault is low and the fault currents are comparatively large. The reduction of the insulation is not considered as a fault until it shows some effects such as excessive current flow or reduction of impedance between conductors or between conductors and earth.

- When a fault occurs on a system, the voltages of the three phases become unbalanced. As the fault currents are large, the apparatus may get damaged. The flow of power is diverted towards the fault which affects the supply to the neighbouring zone.
- A power system consists of generators, transformers, switchgear, transmission and distribution circuits. There is always a possibility in such a large network that some fault will occur in some part of the system. **The maximum possibility of fault occurrence is on transmission lines due to their greater lengths and exposure to atmospheric conditions.**

- The fault can not be totally eliminated from the system but their occurrence can be minimised by improving system design, quality of the equipment and maintenance.
- The faults can be classified according to causes their incidence to :
  1. The breakdown may occur at normal voltage due to deterioration of insulation.
  2. The breakdown may also occur due to damage on account of unpredictable causes which include perching of birds, accidental short circuiting by snakes, kite strings, three branches etc.
  3. The breakdown may occur at abnormal voltages due to switching surges or surges caused by lighting.

The AC faults can also be classified as :

1. single line to ground fault.
2. double line to ground fault
3. three phase fault

that may occur in the system due to unbalance in current and voltage, over voltages, reversal of power, power swings, under frequency, temperature rise and instability.

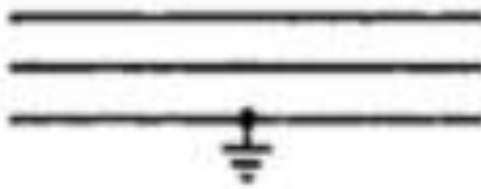
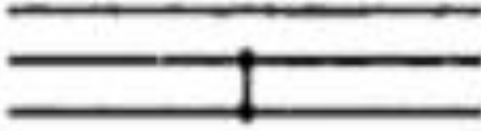
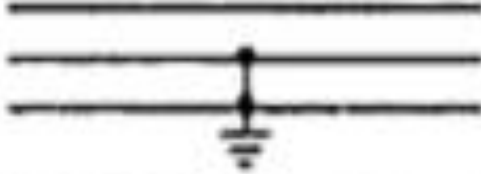
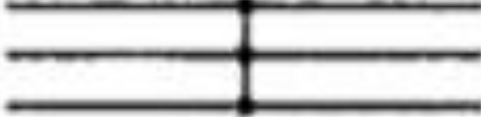
- It may be necessary to know the frequency of the fault occurrence on various parts of the system which help in designing suitable protection circuit. Following table gives us an idea as to how the faults are distributed in the various parts of the system.

Table 1

	<b>Equipment</b>	<b>% of total faults</b>
1)	Overhead lines	50
2)	Switchgear	15
3)	Transformer	12
4)	Cables	10
5)	Miscellaneous	8
6)	Control equipment	3
7)	CTs and PTs	2

- It can be seen from the above table that **maximum number of faults are occurring on overhead lines.**
- In case of three phase system we have :
  1. the breakdown of insulation between one of the phases and earth is known as line to ground fault.
  2. In line to line fault, there is insulation breakdown between either of two phases.
  3. While the insulation breakdown between two phases and earth forms double line to ground fault.
  4. The breakdown of insulation between three phases is nothing but three phase fault.

Following table gives occurrence of these faults.

Type of Fault	Representation	% occurrence
1) Line to Graound (L-G)		85
2) Line to Line (L-L)		8
3) Line to Line to Ground (L-L-G)		5
4) Line to Line to Line (L-L-L)		2 or Less

**Table 2 Type of faults and % of occurrence**

# Sub-transient – transient and steady state cases

- It can be seen from the above table that most of the faults are line to ground faults in case of overhead lines. A large number of these faults are transitory in nature. the word transitory refers to the fault which remains for short duration of time. The fault current varies with time. For example if a twig falls across a line and across arm and burns itself out or just falls down then the fault is transient as it vanishes after few cycles. During first one to three cycles, the fault current is very high but later on decreases very rapidly.



- This zone in which the current is very high but decreases very rapidly is called 'sub transient' state. After these first few cycles, the rate of current decreases is slower. This zone is called 'transient' state. This state remains for several cycles. After the transient state is over, steady state is reached. During the steady state, the rms values of short circuit current remains constant. The circuit breaker operates during transient state.

# Chapter (2) Circuit Breakers

## 2.1 Introduction

A circuit breaker is required to perform the following three duties:

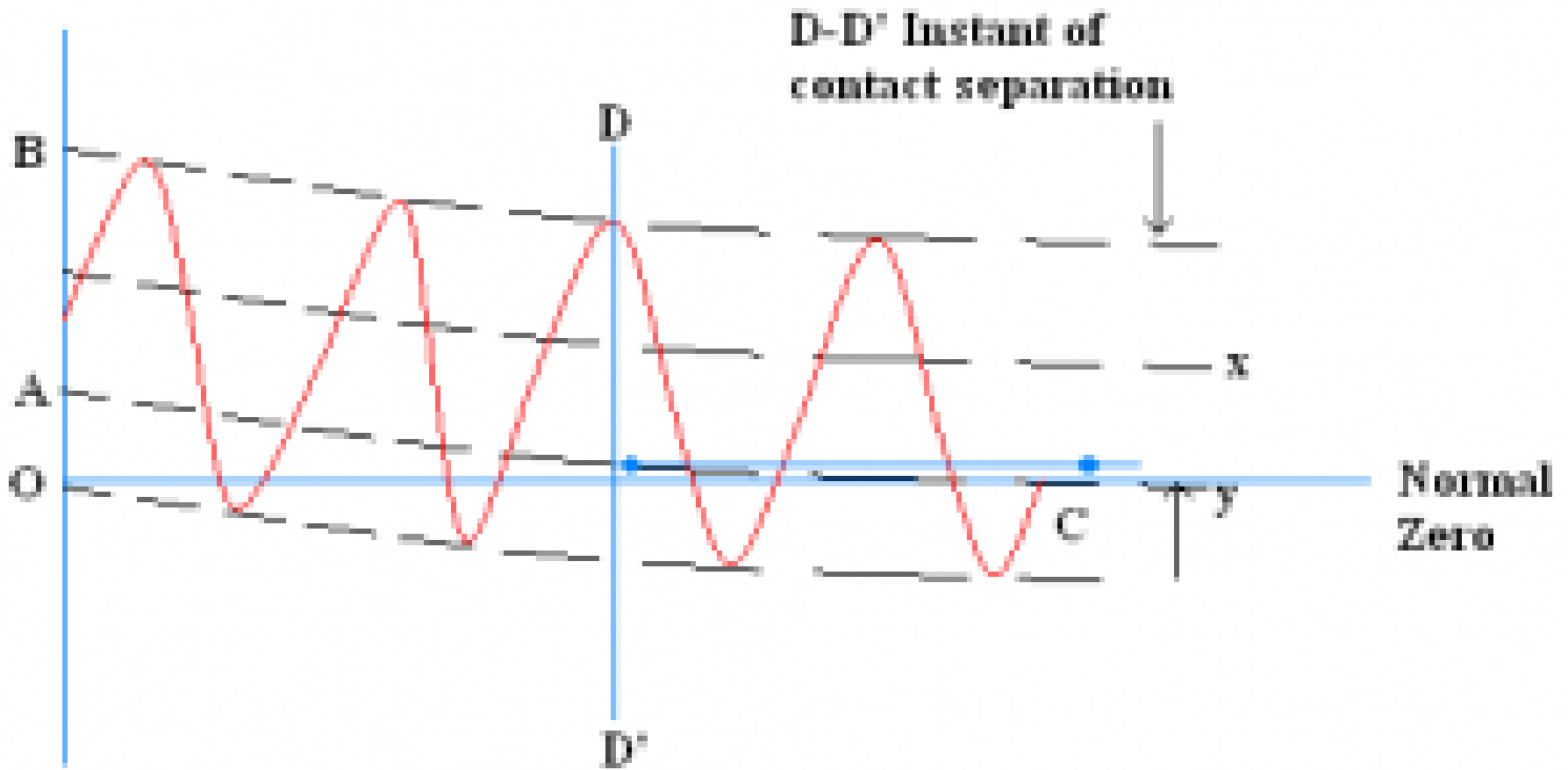
1. It must be capable of opening the faulty circuit and breaking the fault current.
2. It must be capable of being closed on to a fault
3. Must be capable of carrying fault current for a short time while another breaker is clearing the fault.

Depending on the above duties circuit breaker has three ratings breaking capacity, making capacity and short time capacity.

- **BREAKING CAPACITY**

- It is current that a circuit breaker is capable of breaking at a given recovery voltage under specified conditions. **The breaking capacity is always stated at the r.m.s value of fault current at the instant of contact separation.**

When a fault occurs there is considerable asymmetry in the fault current due to presence of d.c component. The d.c component dies away rapidly. The contacts are separated at DD' as shown in fig5



- At this point, fault current has
- $x = \text{max value of a.c component}$
- $y = \text{d.c component}$
- Therefore Symmetrical breaking current = r.m.s value of a.c component =  $x / [2]^{1/2}$
- Asymmetrical breaking current = r.m.s value of a.c component =  $[[x / [2]^{1/2}]^2 + y^2]^{1/2}$
- Breaking capacity is expressed in MVA by taking into account the rated breaking current and rated service voltage. Thus if  $I$  is the rated breaking current in amperes and  $V$  is rated service line voltage in volts, then for a three phase circuit breaking capacity =  $\sqrt{3} * V * I * 10^{-6}$  MVA

- **MAKING CAPACITY**

- The capacity of a breaker to make current depends upon its ability to withstand and close successfully against the effects of electromagnetic forces. These forces are proportional to the square of maximum instantaneous current on closing. So making capacity is stated in terms of a peak value of current. The peak value of current during the first cycle of current wave after the closure of circuit breaker is known as making capacity. To find making capacity multiply symmetrical breaking current by root 2 to convert from r.m.s to peak and then by 1.8 to include the doubling effect of maximum asymmetry. Making capacity =  $2.55 * \text{symmetrical breaking capacity}$ .

- **SHORT TIME RATING**

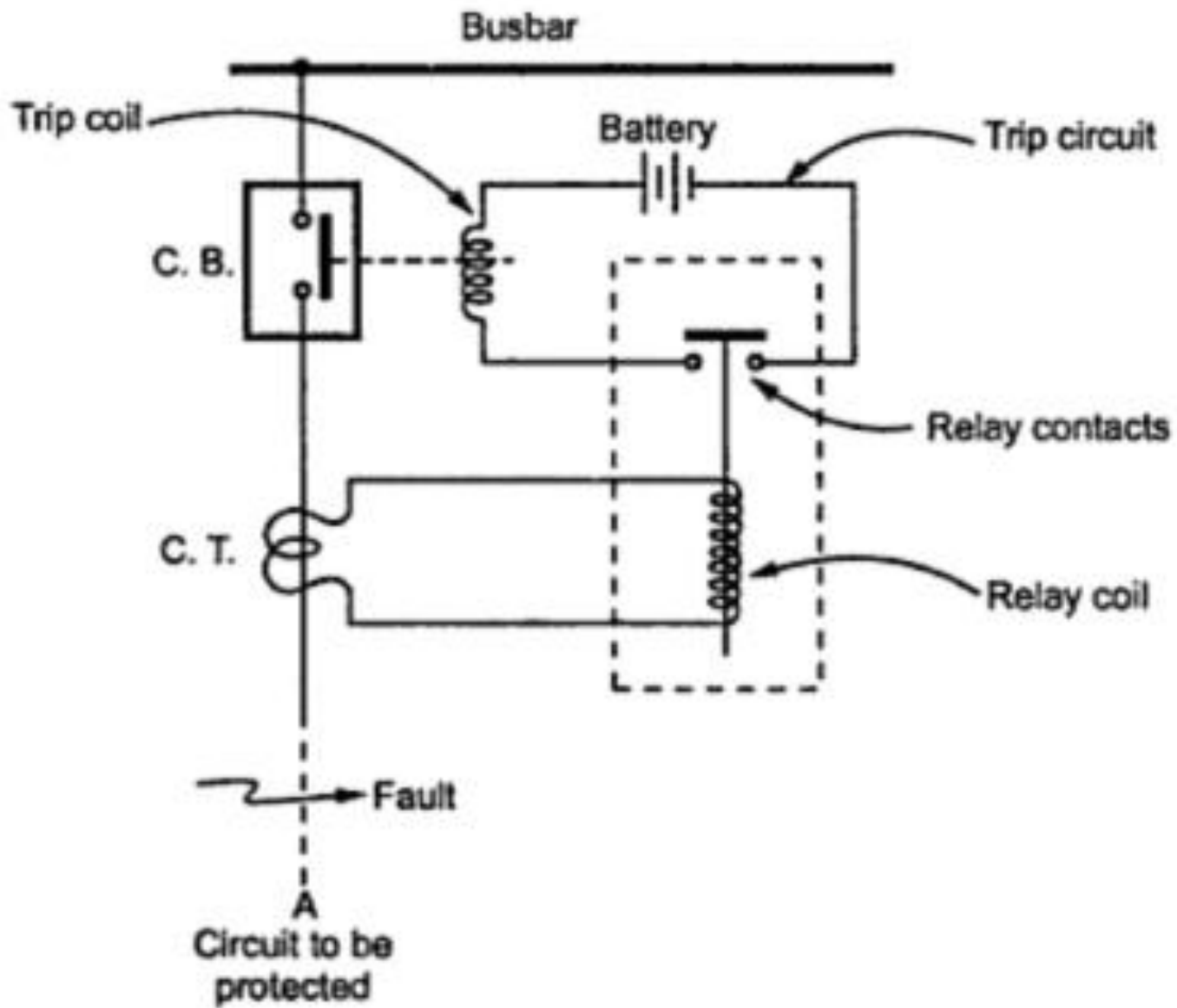
It is the period for which the circuit breaker is able to carry fault current while remaining closed. The fault on the system of very temporary nature persist for 1 or 2 sec after which the fault will be cleared, so the breaker should not be tripped in such situations. This means the circuit breakers should be able to carry high current safely for some specified period while remaining closed. i.e they should have short time rating. It depends on its ability to withstand electromagnetic force effects and temperature rise.

## 2.2 Trip circuit of circuit breakers

Consider a simplified circuit of a typical relay as shown in the Fig. 1 usually the relay circuit is a three phase circuit and the contact circuit of relays is very much complicated. The Fig. 1 shows a single phase simplified circuit to explain the basic action of a relay. Let part A is the circuit to be protected. The current transformer C.T. is connected with its primary in series with the line to be protected. The secondary of C.T. is connected in series with the relay coil. The relay contacts are the part of a trip circuit of a circuit breaker. The trip circuit consists of a trip coil and a battery, in addition to relay contacts. The trip circuit can operate on a.c. or d.c.



If the fault occurs as shown in the Fig. 1, Then current through the line connected to A increases to a very high value. The current transformer senses this current. Accordingly its secondary current increases which is nothing but the current through a relay coil. Thus the relay contacts get closed mechanically under the influence of such a high fault current. Thus the trip circuit of a circuit breaker gets closed and current starts flowing from battery, through trip coil, in a trip circuit. Thus the trip coil of a circuit breaker gets energized. This activates the circuit breaker opening mechanism, making the circuit breaker open. This isolates the faulty part from rest of the healthy system.



**Fig.1 typical relay circuit**

## 2.3 Tripping Schemes in Circuit Breaker

Two schemes are very popularly used for tripping in circuit breakers which are:

1. Relay with make type contact
2. Relay with break time contact

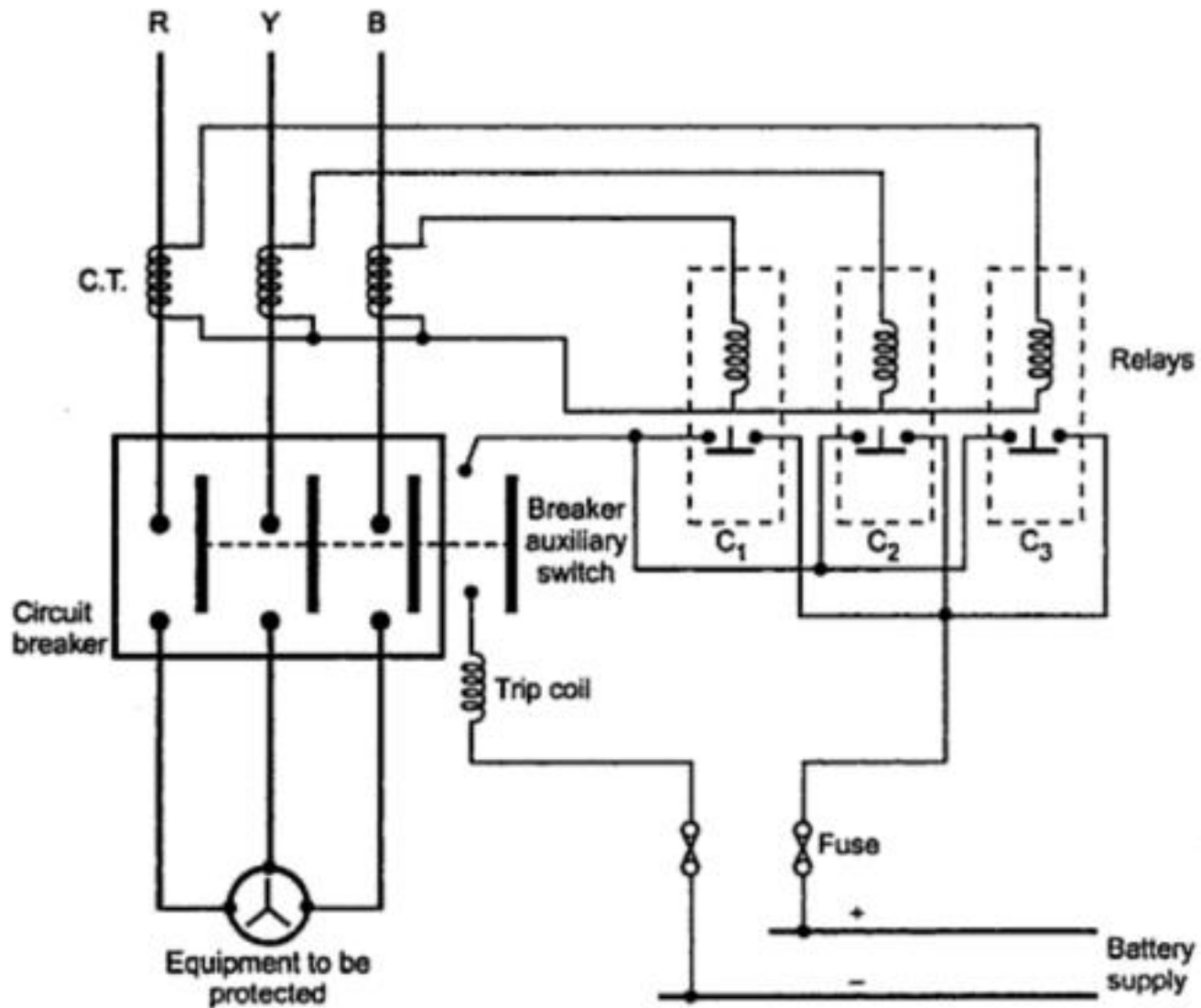
The relay with make type contact requires auxiliary d.c. supply with its operation.

while the relay with break type contact uses the energy from the main supply source for its operation. Let us see the details of these two types of schemes.

## 2.3.1 Relays With Make Type Contact

The schematic diagram representing the arrangement of various elements in a relay with make type contact is shown in the Fig.2.

A separate supply is necessary for the relay operation.  
The relays are connected in star while the relay contacts are connected in parallel. The entire relay contact unit is connected in series with the auxiliary switch, trip coil and the battery. Relay contacts are open in normal position.



**Fig. 2 Relay with make type contact**

- **Operation :** When the fault occurs, the current through relay coils increases to a very high value. Due to this, **the normally open relay contacts  $C_1$ ,  $C_2$  and  $C_3$  get closed.** This activates the trip coil of a circuit breaker. **The auxiliary switch is initially closed along with the circuit breaker.** So when contacts  $C_1$ ,  $C_2$  and  $C_3$  are closed, the current flows through trip coil of circuit breaker. This activates the trip coil which opens the circuit breaker. As auxiliary switch is mechanically coupled with the circuit breaker, it also gets opened. This interrupts the current through trip coil. Thus supply to fault part gets interrupted and trip coil also gets de-energized. **This brings the relay contacts back to normal position.**

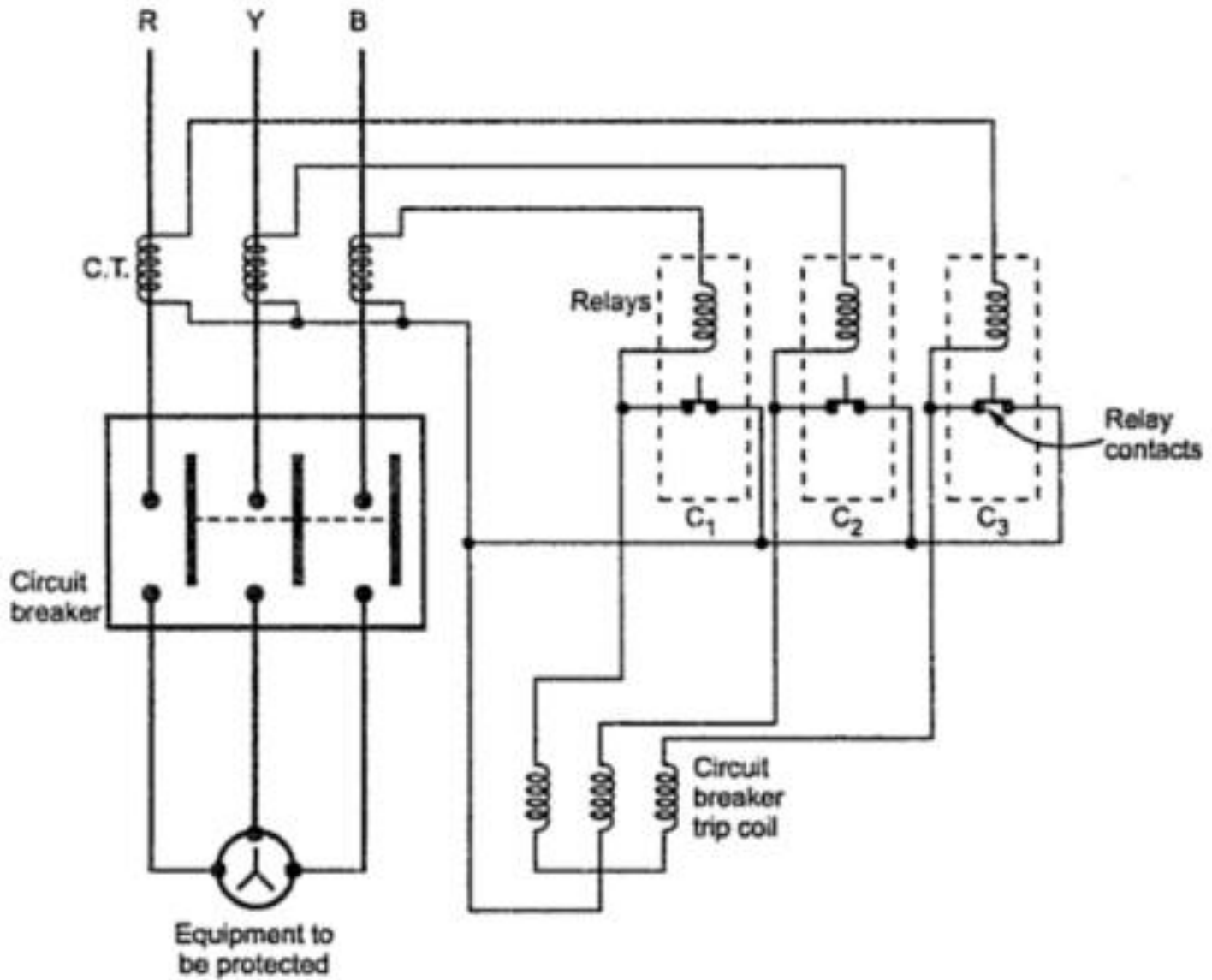
- **Due to auxiliary switch, arcing across relay contacts gets avoided.** As relay contacts are normally open and they 'make' the circuit to open the circuit breaker hence called make type contact relay.

## 2.3.2 Relay With Break Type Contact

The schematic arrangement of various elements in a relay with break type contact is shown in the Fig. 3.

This type of relay does not require external battery supply for the tripping. The current transformers (C.T.s) or potential transformer (P.T.s) are used to derive the energy required for the relay from the main supply source. **The relay using C.T.s to derive operating energy from the supply is shown in the Fig. 3.**

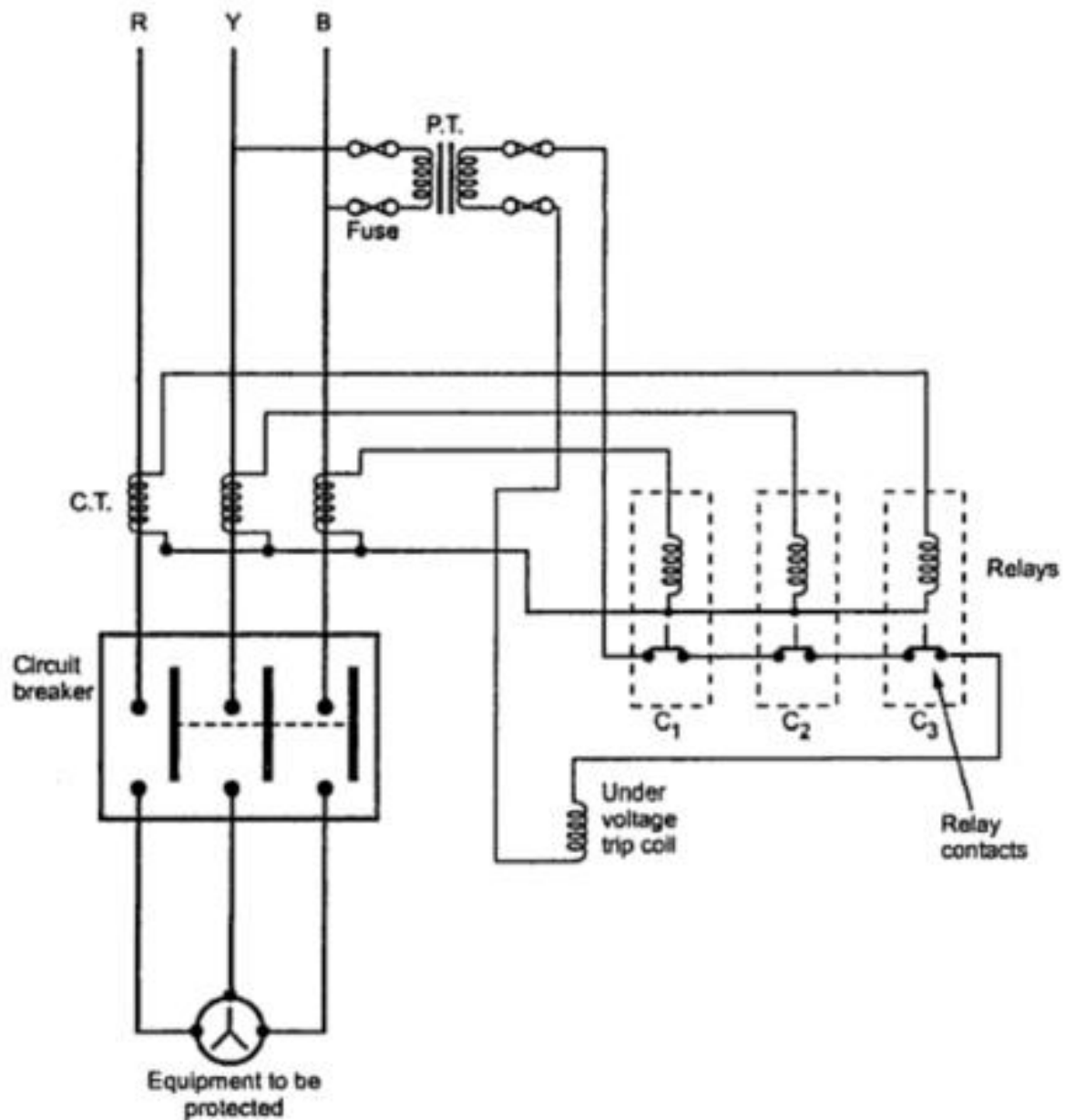




**Fig.3 Relay with break type contact (using C.T.s)**

- In this scheme, the relay coil and trip coil of each are connected in series. The three phases are then connected in star. Under normal working, the relay contacts  $C_1$ ,  $C_2$  and  $C_3$  are closed. The energy for relay coils is derived from supply using C.T.s. The trip coils of circuit breaker are de-energized under normal condition. When the fault occurs, heavy current flows through relay coils due to which relay contacts  $C_1$ ,  $C_2$  and  $C_3$  break. **Thus current flows through trip coils of circuit breaker due to which circuit breaker gets open.**

The Fig. 4 shows the break type contact relay using P.T. to derive energy to keep relay coils energized.



**Fig.4 Relay with break type contact (using P.T.)**

- In this type, in addition to normal trip coils of circuit breaker, an additional undervoltage trip coil is used. All the relay contacts are in series with the undervoltage trip coil. Through potential transformer, for normal voltage, the undervoltage trip coil is kept energized. **When the voltage becomes less than the normal value, the magnetic effect produced by undervoltage trip coil reduced which is responsible for the opening of the circuit breaker.** When fault occurs, the normal trip coils of circuit breaker comes into the picture and are responsible for the opening of the circuit breaker.

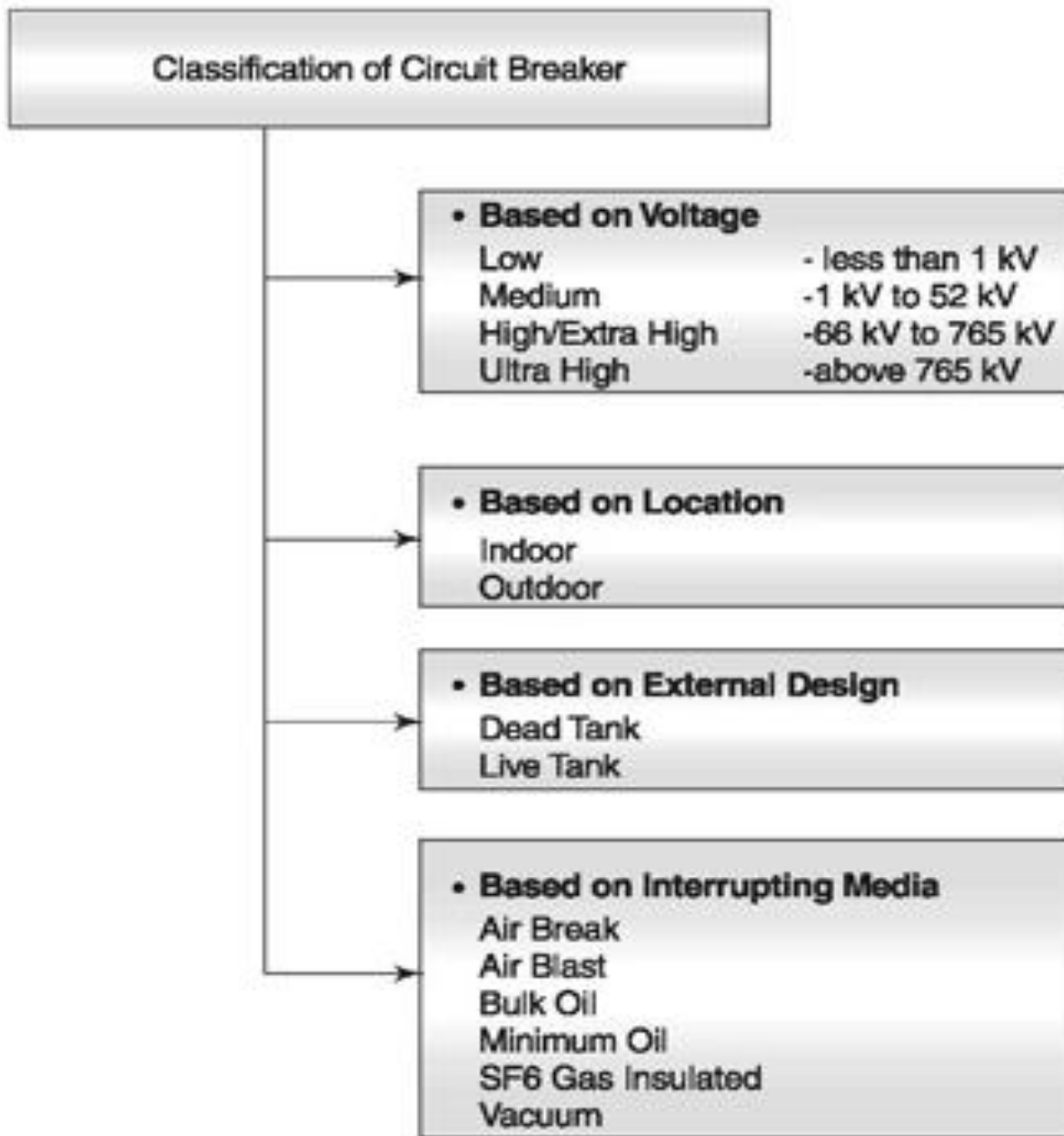
In both the above types of tripping circuit (using C.T. Or P.T.), relay contacts 'break' to cause the circuit breaker operation hence the relay is called break type contact relay.

## 2.4. Classification of Circuit Breakers

Circuit breakers can be arbitrarily classified using criteria such as,

1. intended voltage application,
2. Location of installation (i.e. outdoor, indoor),
3. Their external design characteristics, or perhaps the most important, method and medium used for the current interruption.

This is shown in Fig. 5.





## 2.4.1 Classification by Voltage

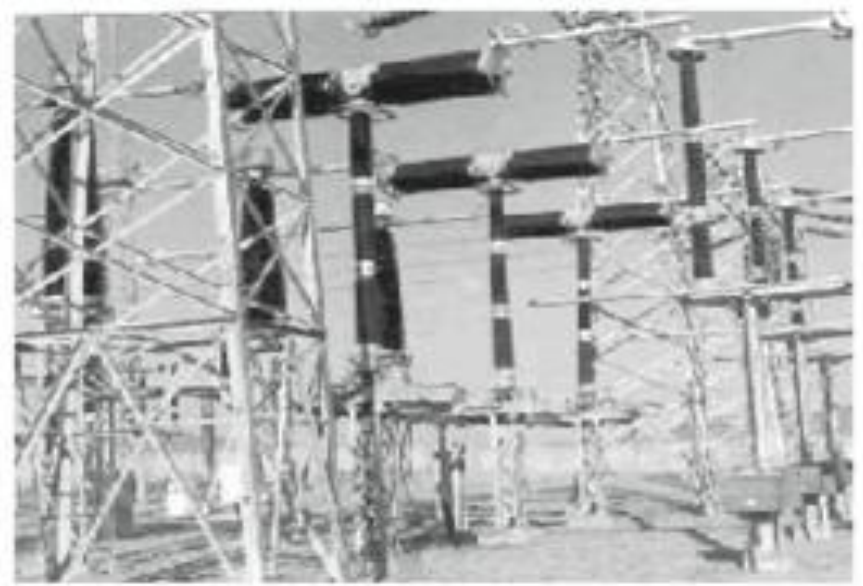
The classification of circuit breakers by its intended application voltage, is normally as given in Fig. 5.

## 2.4.2 Classification by Location

- Switchgears, based on where they are located are classified as, **indoor and outdoor types (Fig.6)**
- **Medium and low voltage switchgears, and high voltage Gas Insulated Switchgears (GIS) are mostly categorised as Indoor switchgears, whereas the switchgears which have air as an external insulating medium, i.e. Air Insulated Switchgear (AIS), are categorised as Outdoor Switchgears.** These are shown in Fig. 6.



33 kV Indoor Type (GIS)



Outdoor Type (AIS)



Dead tank breaker (courtesy ABB)



Live tank breaker (Courtesy BHEL)

## 2.4.3 Classification by External Design

Outdoor circuit breakers can be identified as either dead-tank or live-tank type of circuit breakers, from the point of view of their physical structural design (Fig. 6).

# Dead Tank C.B.

- dead-tank circuit breakers, the switching device is located, with suitable insulator supports, inside a metallic vessel(s) at ground potential and filled with insulating medium.
- In dead-tank circuit breakers, the incoming and outgoing conductors are taken out through suitable insulator bushings,
- and low voltage type current transformers are located at the lower end of both insulator bushings, i.e. at the line side and the load side.

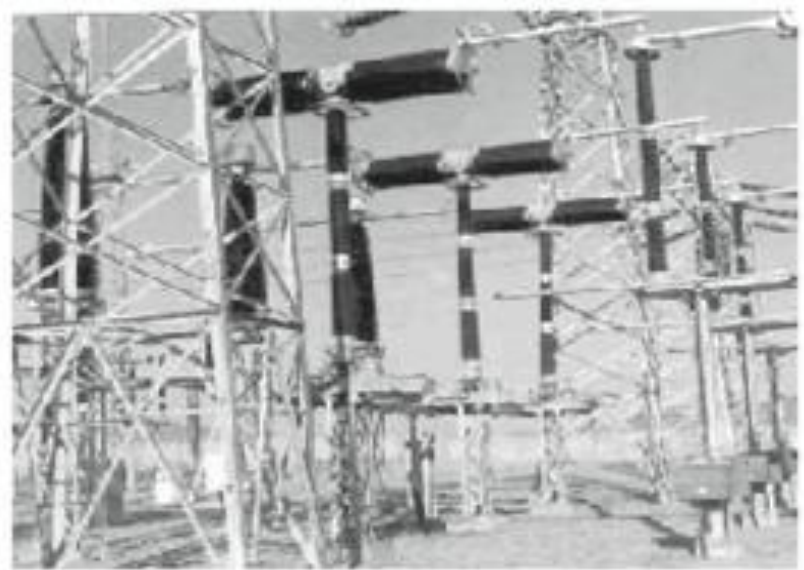
# Live Tank C.B.

In live-tank circuit breakers,

- the interrupter(s) is located in an insulator bushing, at a potential above ground potential.
- The **live-tank circuit breakers** are **cheaper** (with no current transformer),
- and **require less mounting space.**



33 kV Indoor Type (GIS)



Outdoor Type (AIS)



Dead tank breaker (courtesy ABB)



Live tank breaker (Courtesy BHEL)

## 2.4.4 Classification by Interrupting Media

- The interrupting medium has been the vital factor in the evolution of circuit breakers. It dictates the overall design parameters of the breaker.
- The choice of air and oil, as the interrupting media, was predominant till late 70s.
- But today, **vacuum** and **Sulphur hexafluoride (SF6)** are the only dominant interrupting technologies, **for medium** and **high voltage segments** of circuit breaker design respectively.

## 2.5 Techniques to extinguish the arc in C. B.

- Each circuit breaker will be studied thoroughly in the subsequent sections.
- These circuit breaker employ various technique to extinguish the arc resulting from separation of the current carrying contacts.
- The mode of arc extinction is:-
  1. either 'high resistance interruption'
  2. or 'zero-point interruption'.



## 2.5.1 High Resistance Interruption

- **High Resistance Interruption:** In this process the resistance of the arc is increased by lengthening and cooling it to such an extent that the system voltage is no longer able to maintain the arc and the arc gets extinguished. This technique is employed in air break circuit breakers and d.c. circuit breakers.

## 2.5.2 Low Resistance or Zero Point Interruption

- **Low Resistance or Zero Point Interruption:** In this process, the arc gets extinguished at natural current zero of the alternating current wave and is prevented from re-striking again by rapid build-up of dielectric strength of the contacts space. This process is employed in almost all a.c. circuit breakers.

- Each leading manufacturer of circuit breaker develops two or more types of circuit breakers for every voltage class.
- The construction of the circuit breaker depends upon its type (arc-quenching medium), voltage rating and structural form.

- **Air-break circuit breaker** : Utilize air at atmospheric pressure for arc extinction.
- **Air-blast circuit breakers** : Utilize high pressure-compressed air for arc extinction. They need compressed air plant.
- **Bulk-oil and Minimum-oil circuit breaker** : utilize dielectric oil ( Transformer oil ) for arc extinction. In bulk-oil circuit breakers, the contacts are separated inside a steel tank filled with dielectric oil. In minimum oil circuit breakers the contacts are separated in an insulating housing (interrupter) filled with dielectric oil.

- **SF6 circuit breakers** : sulphur-Hexa-Fluoride gas is used for arc extinction. There are two types :
- **Single pressure puffer type SF6 circuit breaker**, in which the entire circuit breaker is filled with SF6 gas at single pressure ( 4 to 6 kg/cm<sup>2</sup>). The pressure and gas flow required for arc extinction is obtained by piston action.
- **Double pressure type SF6 circuit breaker** in which the gas from high-pressure system is released into low pressure system over the arc during the arc quenching process. This type has been superseded by puffer type.

- **Vacuum circuit breaker** : In vacuum circuit breaker the fixed and moving contacts are housed inside a permanently sealed vacuum interrupter. The arc is quenched as the contacts are separated in high vacuum.
- A brief comparison between the different types of circuit breakers is given in table 1. (see the newer post)
- Table 1 Comparison of circuit breakers

Type	Medium	Voltage. Breaking capacity	Design Feature	Remarks
1- Air- break circuit breaker	Air at atmospheric pressure	430-600 V, 5-15-35 MVA Recently 3.6-12 KV, 500 MVA	Incorporates: Arc runners, arc splitters, magnetic coils	Used for medium and low voltage, A.C., D.C., Industrial circuit breakers. Have current limiting
Miniature C.B.	Air at atmospheric pressure	430-600 KV	Small size, current limiting feature	Used for low and medium voltage
2- Tank type oil circuit breaker	Dielectric oil	12-36 KV	One tank up to 36 KV, 3 tank above 36 KV, fitted with arc control devices	Getting obsolete, used up to 12 KV, 500 MVA
3- Minimum oil circuit breaker	Dielectric oil	3.6-245 KV	The circuit breaking chamber is separate from supporting chamber. Small size, arc control device used	Used for metal enclosed switchgear up to 36 KV. Outdoor type between 36 and 245 KV
4- Air blast circuit breaker	Compressed air (20-30 kgf/cm <sup>2</sup> )	245 KV, 35.000 MVA up to 1100 KV, 50.000 MVA, also 36 KV, 500 MVA	Unit type construction, several units per pole, auxiliary compressed air system required	Suitable for all EHV applications, fast opening-closing. Also for arc furnace duty
5- SF6 circuit breaker - single	SF6 gas (5 kgf/cm <sup>2</sup> )	145 KV, 7500 MVA 245 KV, 10.000 MVA 12 KV, 500 MVA 36 KV, 2000 MVA	Live tank/Dead tank design, single pressure type preferred	Suitable for SF6 switchgear, and medium voltage switchgear. EHV circuit breaker. Maintenance free
6- Vacuum circuit breaker	Vacuum	Preferred for indoor switchgear rated up to 36 KV, 750 MVA	Variety of designs, long life, modest maintenance	Suitable for a variety of applications from 3.6 KV up to 36 KV
7- H.V.D.C circuit breaker	Vacuum or SF6	500 KV DC, 15 KA/20 KA	Artificial current zero by switching in capacitors	Recently developed, used in HVDC systems. Installed in USA

## 2.6 Rated characteristic of circuit breakers

- The rating of a circuit breaker denote its capabilities under specified condition of use and behaviour. The following paragraphs are generally based on the recommendation of IEC-56: "High Voltage Alternating Current Circuit-Breakers" and IS-2516: " Specifications of Alternating current circuit-breaker".
- The capabilities of a circuit breaker of a particular type are proved by conducting type tests as per the recommendations of the standards.



## 2.6.1 Rated Voltage

- The rated voltage of a circuit-breaker corresponds to the higher system voltage for which the circuit breaker is intended. The standards values of rated voltages are given in table 2. **The rated voltage is expressed in KVrms** and refers to phase to phase voltage for three-phase circuit. The earlier practice of specifying the rated voltage of a circuit breaker as nominal system voltage is no more followed.

# Table 2 : Rated Voltage of Circuit Breaker

Nominal System Voltage ( KVrms )	Rated Voltage of Circuit Breaker ( KVrms )
1.240	1.246
1.410	1.440
3.300	3.600
6.600	7.200
11.000	12.000
22.000	24.000
33.000	36.000
66.000	72.000
132.000	140.000
220.000	240.000
400.000	420.000
500.000	520.000
750.000	760.000

## 2.6.2 Rated Insulation Level of C.B.

- The rated insulation level of a circuit breaker refers to:-
  1. The power frequency withstand voltage and
  2. Impulse voltage withstand values  
which characterize the insulation of the circuit breaker.

# Causing of Power-frequency over voltages

- Power-frequency over voltages are due to regulation, ferranti effect, higher tap-setting, etc. The circuit breaker should be capable of withstanding the power frequency over-voltages which are likely to occur. **These capabilities are verified by conducting power frequency voltage withstand tests and impulse voltage withstand tests.** The circuit breaker is subjected to impulse over-voltage due causes like lighting surge and switching surge.

- During single-line to ground faults, the voltage of healthy lines to earth increases to  $\sqrt{3}$  time the normal value in the system with insulated neutral. Hence higher values of insulation are recommended for circuit breaker connected in noneffectively earthed systems. The following insulations are provided in the circuit breaker :
  - Insulation between live parts and earth for each pole external and internal.
  - Insulation between poles.
  - Insulation between terminals of the same pole-external and internal

The design of these insulations depends upon the structural form of the circuit breaker and the rated insulation level desired.

## 2.6.3 Rated Frequency

- The standard frequency for a three pole circuit breaker is the frequency of the power system (50/60 HZ). The characteristics like normal current breaking capacity etc. are based on the rated frequency.
- The frequency of the current influences the circuit breaker behaviour as follows:

- The temperature rise of current carrying parts and neighbouring metallic parts is influenced by eddy-current heating . The increase in frequency results in increased eddy currents. Hence, with specified limits of the temperature rise the rated current of a circuit breaker needs de-rating for application on higher frequency.
- The frequency corresponds to the number of current-zeros per second. Since the breaking time of the circuit breaker is associated with the time for half cycles during the arc extinguishing process, the breaking time is influenced by the frequency of current. The breaking time increases with reducing in frequency.

- The increase in frequency influences the TRV and rate-of-rise TRV. Hence a circuit breaker designed and rated for a certain frequency cannot be recommended for other frequencies unless capabilities are proved for those frequencies.
- The d.c. circuit breakers generally adopt a different principle of arc extinction and have different construction than a.c. circuit breaker



## 2.6.4 Rated Normal Current (Rated Current)

- The rated normal current of a circuit breaker is the r.m.s value of the current which the circuit breaker can carry continuously and with temperature rise of the various parts within specified limits. Preferred values of rated current in  $A_{rms}$  are 400, 630, 800, 1250, 1600, 2000, 2500, 3150, and 4000.

- The design of contacts and other current carrying parts in the interrupter of the circuit breaker are generally based on the limits of the temperature rise. For a given cross-section of the conductor and a certain value of current, the temperature rise depends upon the conductivity of the material. Hence, high conductivity material is preferred for current carrying parts. The cross-section of the conductors should be increased for materials with lower conductivity. The use of magnetic materials in close circuits should be avoided to prevent heating due to hysteresis loss and eddy currents. The rated current of a circuit breaker is verified by conducting temperature rise tests.

## 2.6.5 Rated Short Circuit Breaking Current

- The rated short circuit breaking current of a circuit breaker is the highest rms value of short circuit current which the circuit breaker is capable of breaking under specified conditions of transient recovery voltage and power frequency voltage. It is expressed in KA rms at contact separation.

- Referring to Fig. 2, the short circuit current has a certain value at the instant of contact separation, ( $t = T_1$ ). The breaking current refers to value of current at the instant of the contact separation.

The transient recovery voltage refers to the transient voltage appearing across the circuit breaker pole immediately after the arc interruption.

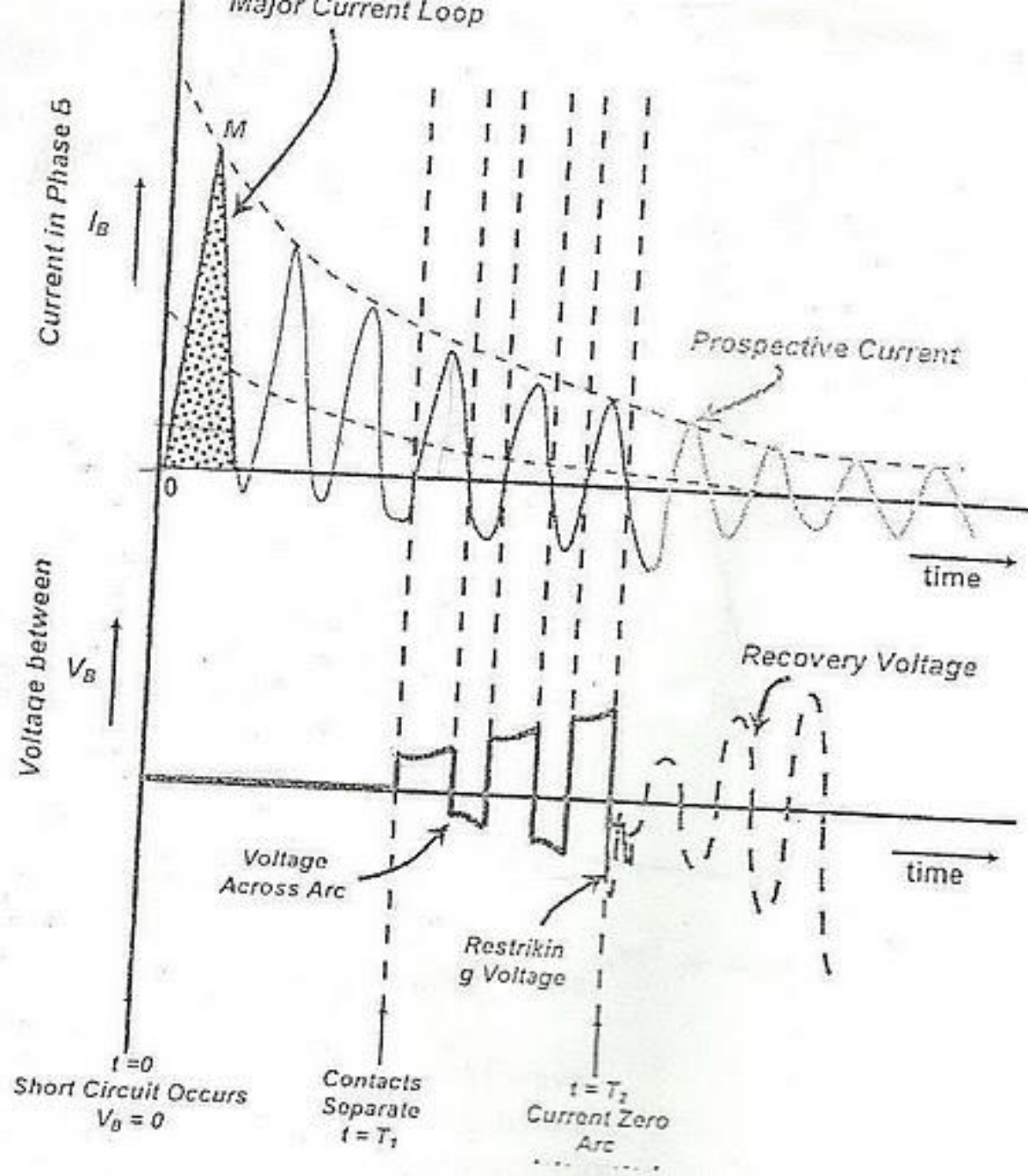


Figure 2 Oscillogram of Current and Voltage during fault clearing

- The rated values of transient recovery voltage are specified for various rated voltage of circuit breakers. For specified conditions of rated TRV and rated power frequency recovery voltage, a circuit breaker has a certain limit of breaking current.
- This limit is determined by conducting short circuit type tests on the circuit breaker. The waveforms of short circuit current are obtained during the breaking test. **The evaluation of the breaking current is explained in Fig. 3. The breaking current is expressed by two values :**



1. The r.m.s value of a.c. component at the instant of contact separation  $E$ , given by  $(I_{dc} / \text{Square root of } 2)$
2. The percentage d.c. component at the instant of contact separation given by  $(I_{dc} \times 100 / I_{Ac})$

The r.m.s values of a.c. components are expressed in KA. the standard values being 8, 10, 12.5, 16, 20, 25, 31.5, 40, 45, 63, 80 and 100KA.

The earlier practice was to express the rated breaking capacity of a circuit breaker in terms of MVA given as follows

$$\text{MVA} = \sqrt{3} \times \text{KV} \times \text{KA}$$

Where

MVA = Breaking capacity of a circuit breaker

kV = Rated voltage

kA = Rated breaking current



- This practice of specifying the breaking capacity in terms of MVA is convenient while calculating the fault levels. However, as per the revised standards, the breaking capacity is expressed in KA for specified conditions of TRV and this method takes into account both breaking current and TRV.
- While selecting the circuit breaker for a particular location in the power system the fault level at that location is determined. The rated breaking current can then be selected from standard range.

## 2.6.6 Rated Short Circuit Making Current

- It may so happen that circuit breaker may close on an existing fault. In such cases the current increase to the maximum value at the peak of first current loop. The circuit breaker should be able to close without hesitation as contact touch. The circuit breaker should be able to withstand the high mechanical forces during such a closure. These capabilities are proved by carrying out making current test. The rated short circuit making current of a circuit breaker is the peak value of first current loop of short circuit current ( $I_{pk}$ ) which the circuit breaker is capable of making at its rated voltage.

- The rated short circuit making current should be least 2.5 times the r.m.s. value of a.c. component of rated breaking current .
- Rated making current =  $1.8 \times \sqrt{2} \times$  Rated short circuit breaking  
=  $2.5 \times$  Rated short circuit breaking current
- In the above equation the factor  $\sqrt{2}$  convert the r.m.s value to peak value. Factor 1.8 takes into account the doubling effect of short circuit current with consideration to slight drop in current during the first quarter cycle .

## 2.6.7. Circuit Breaker Time ( total break time)

- Fault clearing time is the sum of "relay time" and "circuit breaker time". Circuit breaker time is also called "total break time"
- The rapid fault clearing of extra high voltage transmission lines improves the power system stability. Hence, faster relaying and fast circuit breaker are preferred for extra high voltage transmission lines, where the circuit breaker time being in order of 2.5 cycles.

Item		Unit	Technical Data			
			LW10-252 (CY/CYT)		LW10B-363 (CYT)	LW10B-550 (CYT/ABB)
Rated voltage		kV	252		363	550
Rated frequency		Hz	50			
Rated current		A	3150,4000			
Rated short circuit breaking current		kA	40/50		63	63
Rated short line fault breaking current		kA	36/45		56.7	56.7
Rated out of phase breaking current		kA	10/12.5		15.75	15.75
Rated peak withstand current		kA	100/125		160	160
Rated short circuit making current (peak)		kA	100/125		160	160
Rated short time withstand current		kA	40/50		63	63
Rated duration of short circuit		S	3			
Rated line charging breaking current (r.m.s)		A	160		500	500
Breaking time of rated short circuit current		times	20			
Mechanical endurance		times	5000/1000			
Rated SF <sub>6</sub> gas pressure at 20 °C		Mpa	0.4/0.6		0.6	0.6
SF <sub>6</sub> gas moisture content (Ex-work)		PPM	≤150			
SF <sub>6</sub> gas leakage rate (per year)		%	≤1			
SF <sub>6</sub> gas weight (per pole)		kg	6 (without closing resistance)/10(with closing resistance)	12 (without closing resistance)/15(with closing resistance)	20 (without closing resistance)/25(with closing resistance)	
Circuit Breaker weight (per pole)		kg	1600 (without closing resistance)/1800(with closing resistance)	2530 (without closing resistance)/3180(with closing resistance)	2840(without closing resistance)/3800(with closing resistance)	
Operation force for opening/closing		kN	76/38	130/60	130/60	
Terminal load	Longitudinal	N	2250	1500	2800	
	Horizontal	N	1768	1000	2400	
	Vertical	N	1250	1250		

- For distribution system, such a fast clearing is not necessary. Discrimination is obtained by "graded time lag". Hence, slower circuit breaker, 3 to 5 cycles, are used.
- Total breaking time varies between 80-120 ms for circuit breaker up to 12KV and 40-80 ms for circuit breaker above 36KV. It is less than 60 ms for 145KV, less than 50 ms for 420 KV circuit breaker.

# Fault clearing Time

- Remember the following time events :
- **Fault clearing time** = relay time + circuit breaker time
- **Relay time** = instant of fault **to** closure of trip circuit
- **Circuit breaker time** = opening time + arcing

# Chapter (3) Types of Circuit Breakers

## 3.1 Air break circuit breaker

- The air at atmospheric pressure is used as an arc extinguishing medium in Air-Break Circuit-Breakers. **These circuit breakers employ the high resistance interruption principle.** The arc is rapidly lengthened by means of the arc runners and arc chutes and the resistance of the arc is increased by cooling, lengthening and splitting the arc. The arc resistance increases to such an extent that the voltage drop across the arc becomes more than the supply voltage and the arc gets extinguished. Magnetic field is utilized for lengthening the arc in high voltage air-break circuit-breakers.



- Air-break circuit breakers are used in d.c. circuit and a.c. circuits up to 12KV.
- The air-break circuit breakers are generally indoor type and installed on vertical panels or indoor draw-out type switchgear.
- A.C. air circuit breaker are widely used in indoor medium voltage and low voltage switchgear. Typical reference values of ratings of air-break circuit breaker are :
  - 460 V , 400-3500 A, 40-75 KA
  - 3.3 KV , 400-3500 A, 13.1-31.5 KA
  - 6.6 KV , 400-2400 A, 13.1-20 KA

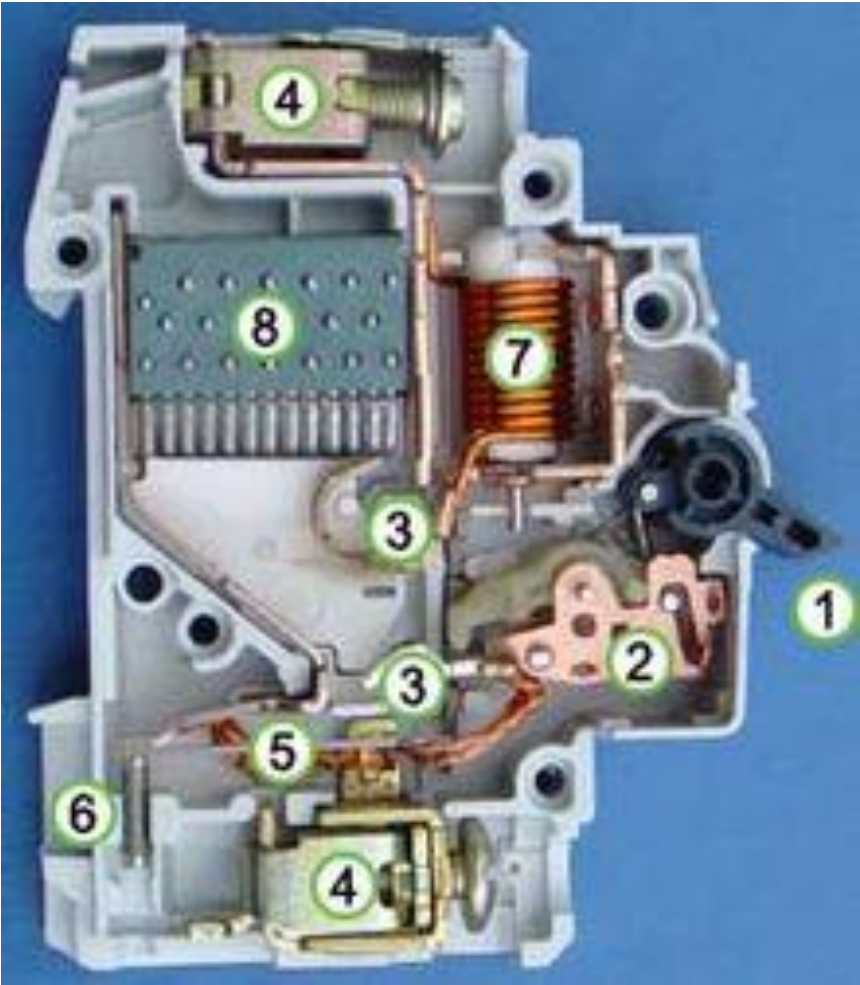
### 3.1.1 Construction of Air-break Circuit-breaker

- In the air-break circuit-breaker the contact separation and arc extinction takes place in air at atmospheric pressure. As the contacts are opened, arc is drawn between them. The arc core is a conducting 'path' of plasma. The surrounding medium contains ionized air. By cooling the arc, the diameter of arc core is reduced. The arc is extinguished by lengthening the arc, cooling the arc and splitting the arc. The arc resistance is increased to such an extent that the system voltage cannot maintain the arc and the arc get extinguished.

- Figure 4 illustrates the normal arrangement of an air break circuit breaker.
- This type of breaker is used for medium and low voltages.



**An air circuit breaker for low voltage (less than 1000 volts) power distribution switchgear**



The 10 ampere DIN rail-mounted thermal-magnetic miniature circuit breaker is the most common style in modern domestic consumer units and commercial electrical distribution boards throughout Europe. The design includes the following components:

1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off/tripped).
2. Actuator mechanism - forces the contacts together or apart.
3. Contacts - Allow current when touching and break the current when moved apart.
4. Terminals
5. Bimetallic strip.
6. Calibration screw - allows the manufacturer to precisely adjust the trip current of the device after assembly.
7. Solenoid
8. Arc divider/extinguisher

- There are two sets of contacts : Main contacts (1) and Arcing contacts (2). Main contacts conduct the current in closed position of the breaker. They have low contact resistance and are silver plated. The arcing contacts (2) are hard, heat resistance and are usually of copper alloy. While opening the contacts, the main contacts dislodge first. The current is shifted to the arcing contacts. The arcing contacts dislodge later and arc is drawn between them (3). This arc is forced upwards by the electromagnetic forces and thermal action. The arc ends travel along the arc Runners (Arcing horns). The arc moves upwards and is split by arc splitter plates (arc chutes) (5) as shown by the arrow (4). The arc extinguished by lengthening, cooling, splitting etc. In some breakers the arc is drawn in the direction of the splitter by magnetic field.

- Furthermore, air-break circuit-breaker have been developed with current limiting feature, magnetic blow-up of arc, etc.
- Air break a.c. circuit breakers are widely used for industrial switchgear, auxiliary switchgear in generation station. Air break principle employing lengthening of arc, arc runners, magnetic blow-ups are used for d.c. circuit breaker up to 15 KV.



## 5.1.2 Miniature and Molded-Case Circuit Breaker

- These are used extensively in low voltage domestic, commercial and industrial applications. They replace conventional fuses and combine the features of a good HRC fuse and a good switch. Figure 5 gives the internal details of a thermal magnetic miniature circuit breaker. For normal operation, it is used as a switch. During over loads or faults, it automatically trips off. The tripping mechanism is actuated by magnetic (part 7) and thermal sensing devices (part5) provide within the MVB.



**Figure 5 The internal details of a 10 ampere European DIN rail mounted thermal-magnetic circuit breaker**

## **Figure contents :**

- 1. Actuator lever - used to manually trip and reset the circuit breaker. Also indicates the status of the circuit breaker (On or Off /tripped). Most breakers are designed so they can still trip even if the lever is held or locked in the On position. This is sometimes referred to as "free trip" or "position trip" operation.**
- 2. Actuator mechanism - forces the contacts together or apart.**
- 3. contacts - Allow current to flow when touching and break the flow of current when moved apart.**
- 4. Terminals**
- 5. Bimetallic strip**
- 6. calibration screw - Allows the manufacture to precisely adjust the trip current of the device after assembly.**
- 7. Solenoid**
- 8. Arc divider / extinguished**

## Typical Rating of MCB :

Current Rating : 5, 10, 15, 20, 30, 40, 50, 60 Amp.  
also, 0.5, 0.75, 1, 2, 2.5, 3, 3.5, 6, 7.5, 8, 10, 12,  
25, 35, 45, 55 Amp.

Voltage Rating : 240 V/415 V AC; 50 V/11 V DC

Rupturing Capacity : AC: 3 KA at 415 V

DC: 3 KA at 50 V ( non-inductive),  
1 KA at 110 V (non-inductive).

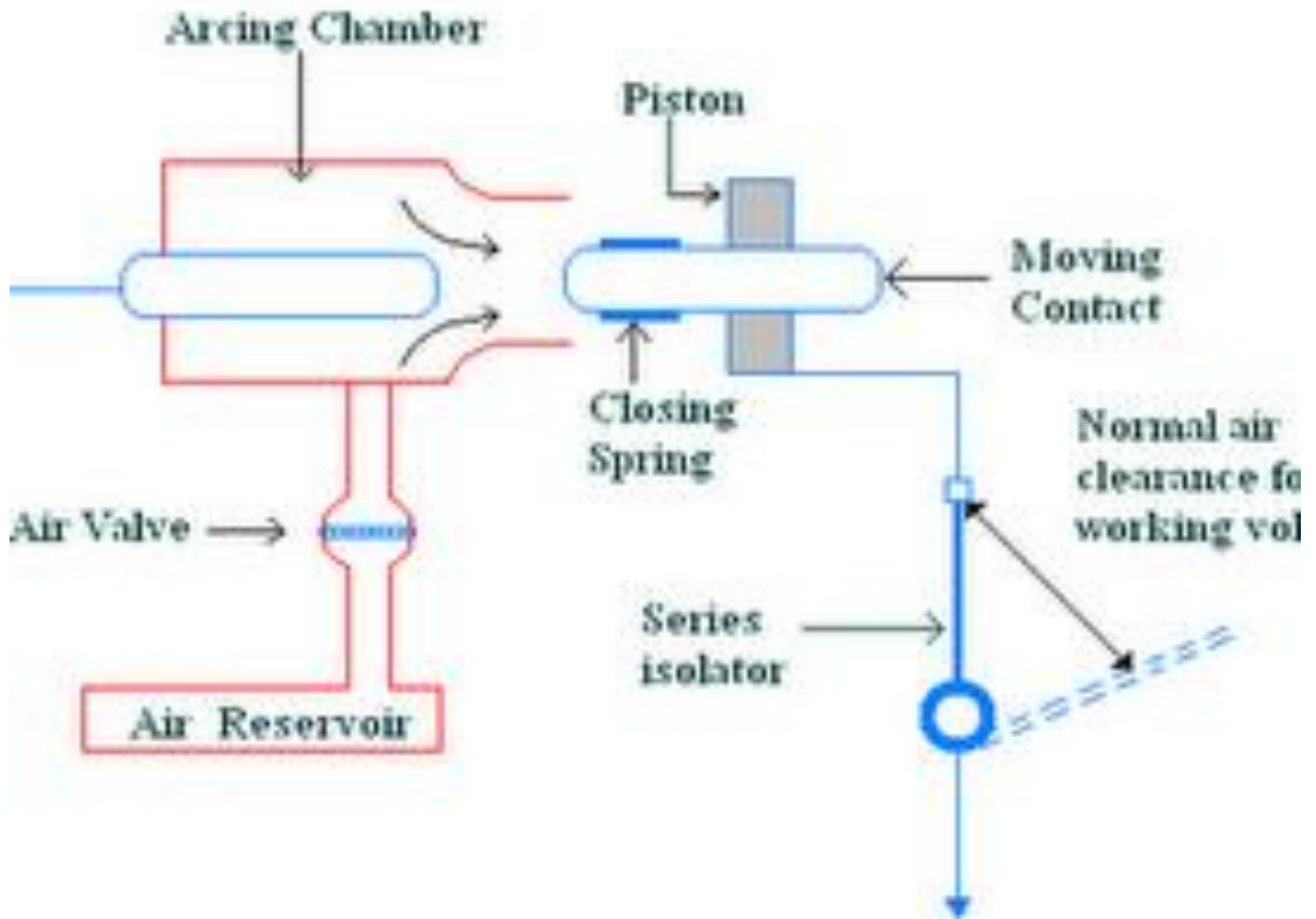
- 5. 2. Air-Blast Circuit-Breaker

- 5.2.1 Introduction

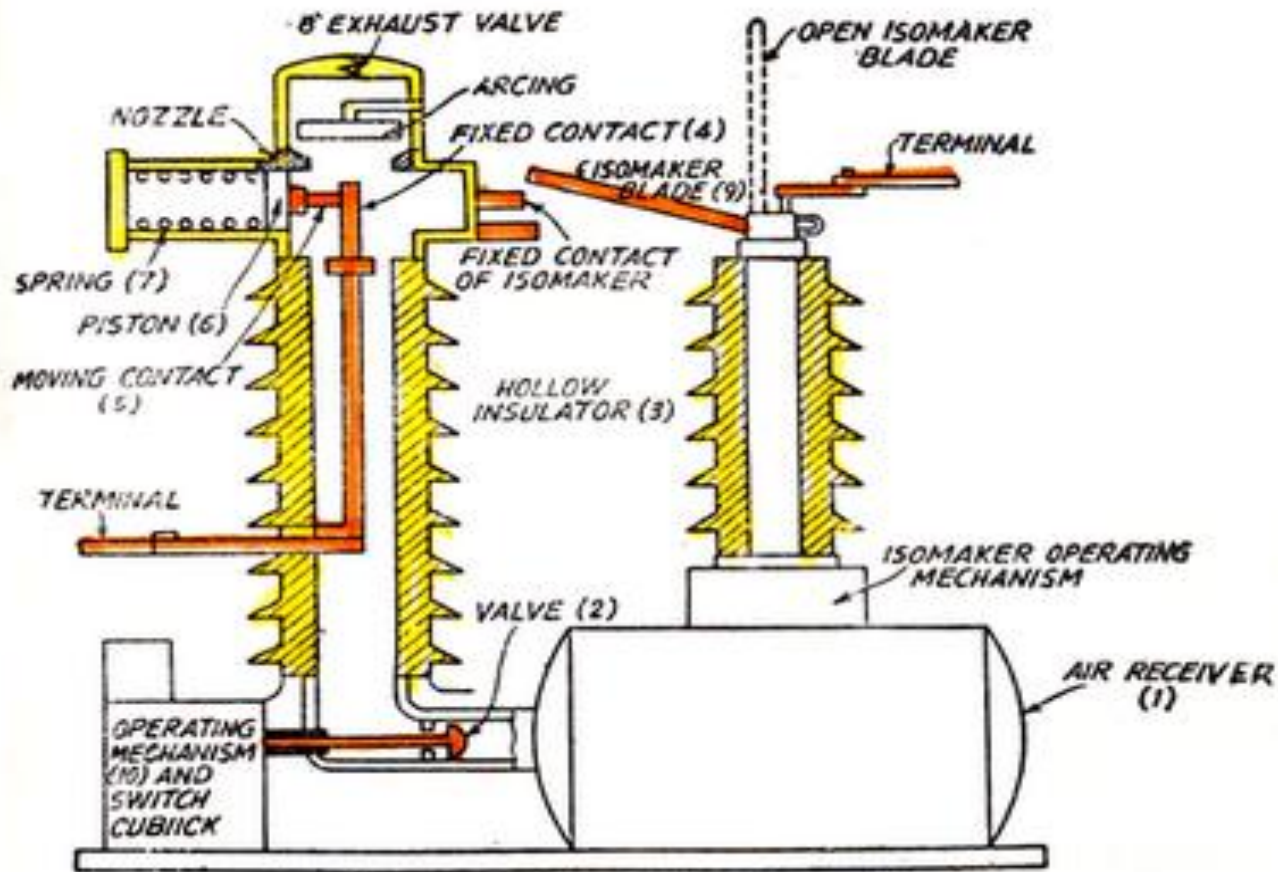
Air blast circuit breakers are used today from 11 to 1100 KV, for various application. They offer several advantages such as faster operations, suitability for related operation, auto-reclosure, unit type multi-break construction, simple, assembly, modest maintenance, etc. A compressor plant is necessary to maintain high air pressure in the receiver. Air-blast circuit breakers operates repeatedly. Air-blast circuit breakers are used for interconnected lines and important lines when rapid operation is desired.

## 5.2.2 Construction of Air-Blast Circuit-Breaker

- In air blast circuit breaker (also called compressed air circuit breaker) high pressure air is forced on the arc through a nozzle at the instant of contact separation. The ionized medium between the contacts is blown away by the blast of the air. After the arc extinction the chamber is filled with high pressure air, which prevents restrike. **In some low capacity circuit breakers, the isolator is an integral part of the circuit breaker. The circuit breaker opens and immediately after that the isolator opens, to provide addition gap.**
- **In EHV circuit of today, isolators are generally independently mounted (Fig. 6).**



( a ) Principle



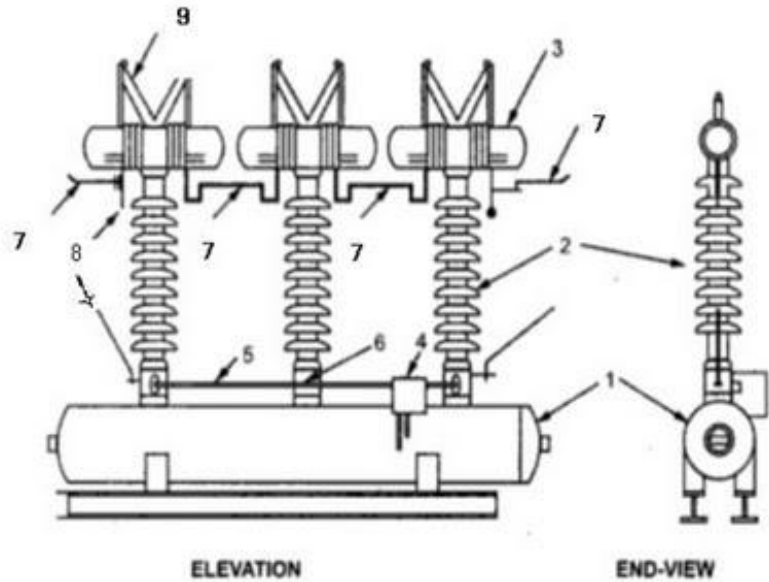
- |                          |                    |                      |
|--------------------------|--------------------|----------------------|
| 1. Air receiver,         | 2. Valve,          | 3. Hollow insulator. |
| 4. Fixed contact,        | 5. Moving contact, | 6. Piston.           |
| 7. Spring,               | 8. Exhaust valve,  | 9. Isomaker,         |
| 10. Operating mechanism. |                    |                      |

25 kV Single Phase Air Circuit Breaker.

( b ) Schematic construction



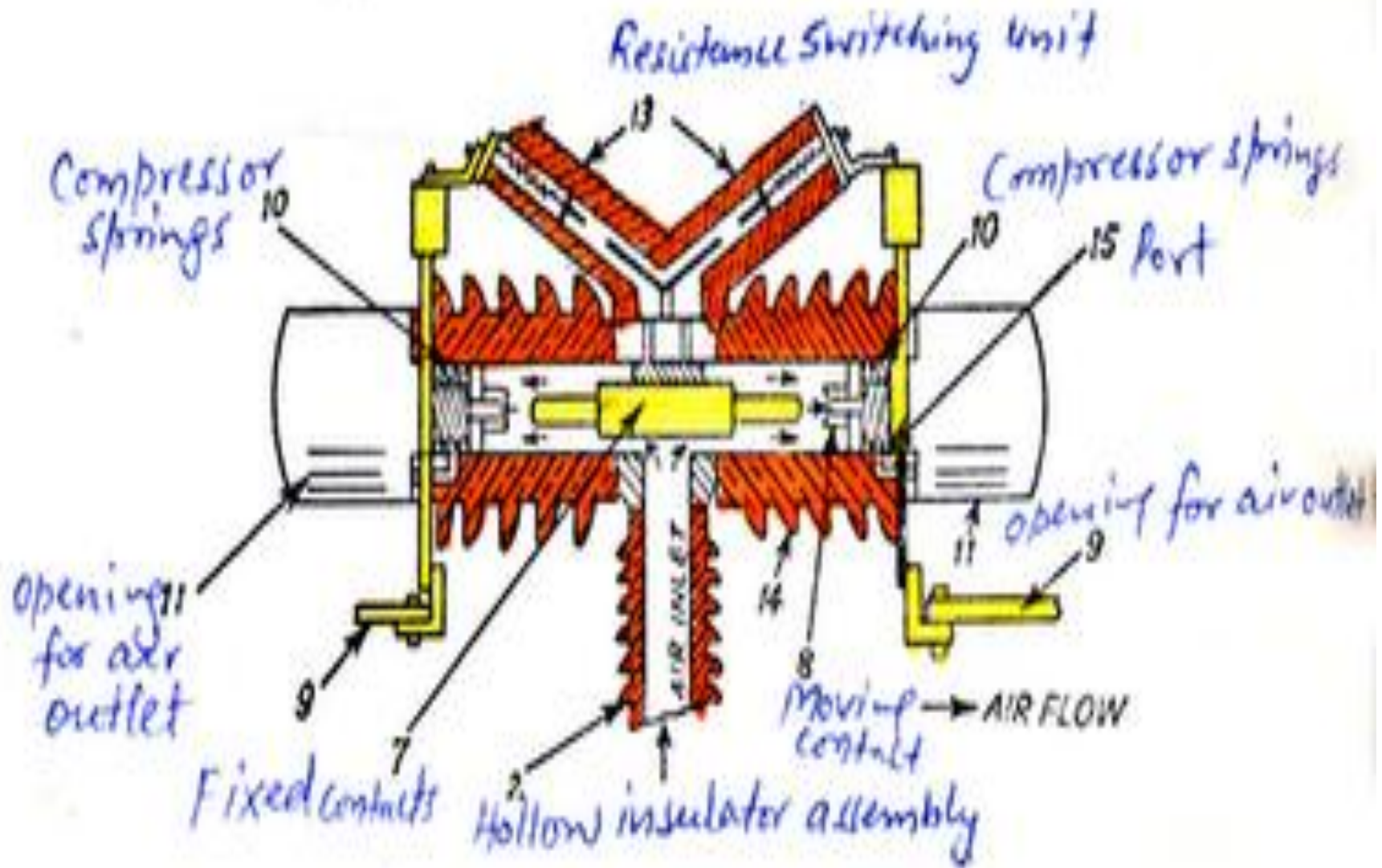
Figure 7 shows one pole of the EHV air blast circuit breaker. In the complete assembly there are three identical poles.



1. Tank air reservoir
2. Hollow insulator assembly
3. Double arc extinction chamber
4. Pneumatic operation mechanism
5. Operation rod
6. Pneumatic valve
7. Connection for current
8. Arcing horns
9. Resistance switching unit

- **Description** : High pressure air between 20 to  $\text{kgf/cm}^2$  , is is stored in the air reservoir (item 1 in Fig. 7). Air is taken from compressed air system. Three hollow insulator columns (item 2) are mounted on the resrvoir with valves (6) at their base. The double arc extinguishing chambers (3) are mounted on the top of the hollow insulator chambers. The current carrying parts (7) connect the three arc extinction chambers to each other in series and the pole to the neighbouring equipment. since there exist a very high voltage between the conductor and the air reservoir, the entire arc extinction chamber assembly is mounted on insulators.

- The details of the double arc extinction chambers (3) are shown in Fig. 8. Since there are three double arc extinction poles in series, there are six breakers per pole. Each arc extinction chamber (Fig. 8) consists of one twin fixed contact. There are two moving contacts which are shown in the closing process. The moving contacts can move axially so as to open or close. Its position open or close depends on air pressure and spring pressure.



**Figure 8 Extra high voltage air blast circuit breaker**

- The operation mechanism (item 4 in Fig. 7) operates the rods (item 5) when it gets a pneumatic or electrical signal. The valves (6) open so as to send the high pressure air in the hollow of the insulator. The high pressure air rapidly enters the double arc extinction chamber. As the air enters into the arc extinction chamber the pressure on the moving contacts becomes more than spring pressure and contacts open.
- The contacts travel through a short distance against the spring pressure. At the end of contacts travel the part for outgoing air is closed by the moving contacts and the entire arc extinction chamber is filled with high pressure air, as the air is not allowed to go out. However, during the arcing period the air goes out through the openings and takes away the ionized air of arc.

- While closing, the valve (6) is turned so as to close connection between the hollow of the insulator and the reservoir. The valve lets the air from the hollow insulator to the atmosphere. As a result the pressure of air in the arc extinction chamber (3) is dropped down to the atmospheric pressure and the moving contacts close over the fixed contacts by virtue of the spring pressure. the opening is fast because the air takes a negligible time to travel from the reservoir to the moving contact. The arc is extinguished within a cycle. Therefore, air blast circuit breaker is very fast in breaking the current.

- Closing is also fast because the pressure in the arc extinction chamber drops immediately as the value (6) operates and the contacts close by virtue of the spring pressure.
- The construction described below applies to air-blast circuit-breakers for EHV applications, for voltages above 145 KV. For voltages of 420 KV and more, the construction is modified by adding required number of arc interrupting chambers in series.
- Air blast circuit breaker requires an auxiliary compressed air system.
- Air blast circuit breakers for 12 KV are generally having a different type of construction. Air blast circuit breakers are preferred for furnace duty and traction system are not satisfactory for such duties.



- Typical rating of Air Blast Circuit Breaker are :
- 12 KV, 40 KA
- 22 KV, 40KA
- 145 KV, 40 KA, 3 cycles
- 245 KV, 40 KA, 50 KA, 2.5 cycles
- 420 KV, 40 KA, 50 KA, 63.5 KA, 2 cycles
- The grading capacitors are connected across the interrupter unit for the equal distribution of voltage between the units. closing resistors (Fig. 9) are connected across the interrupter units for limiting the over voltages during closing operation. Opening resistors are connected across the interrupter units to make the circuit breakers restrike free.

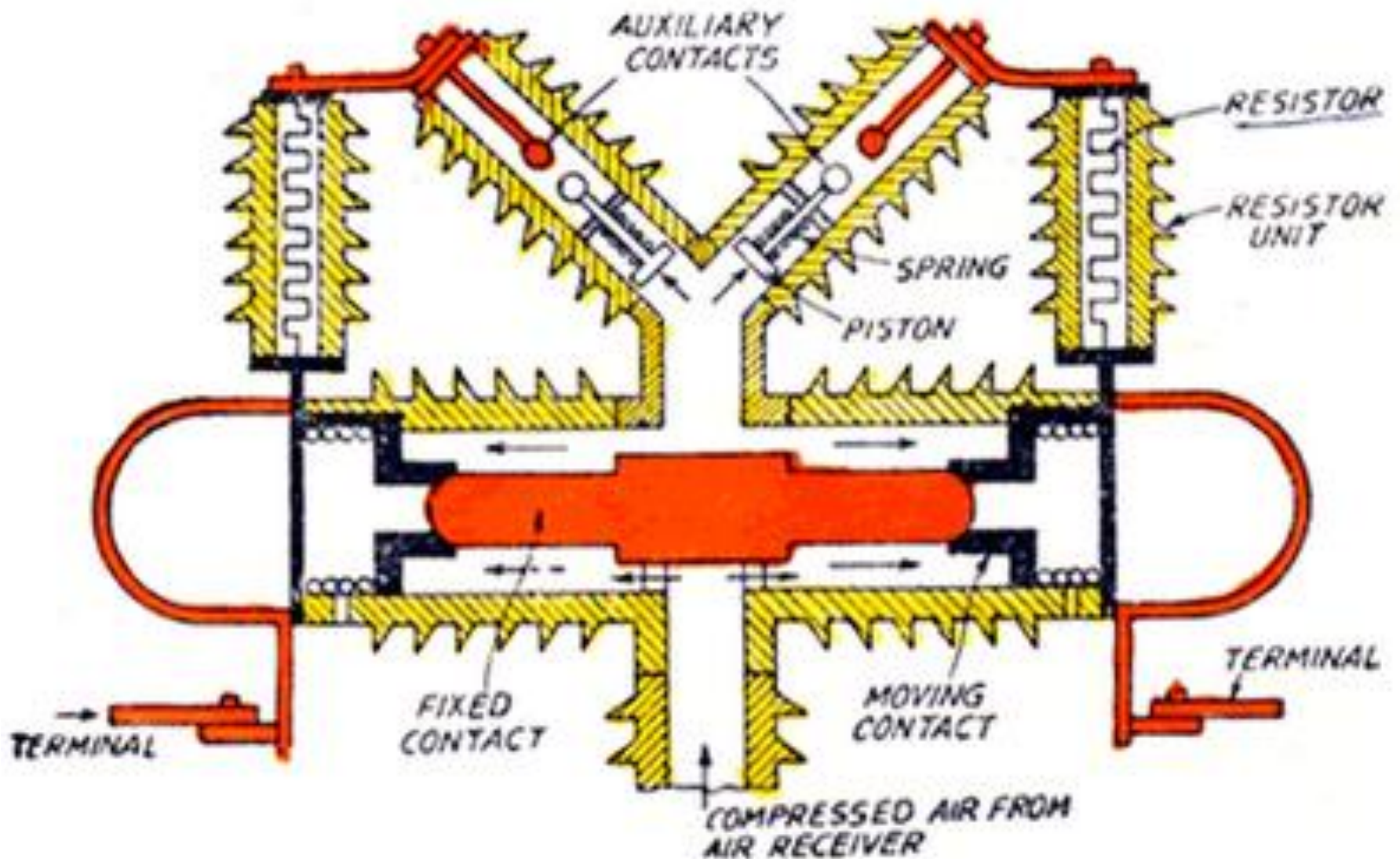
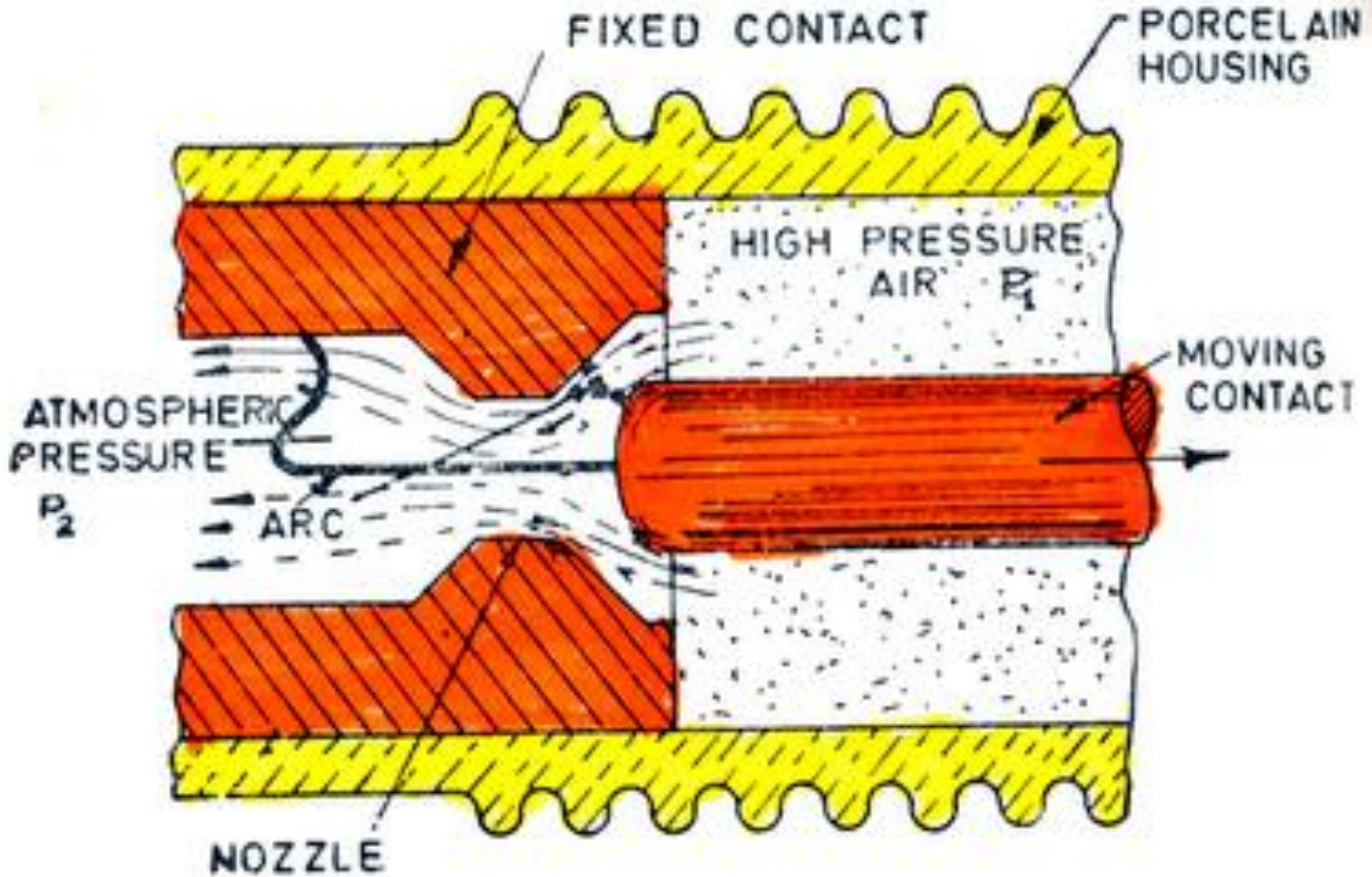


Figure 9 Configuration of switching resistor

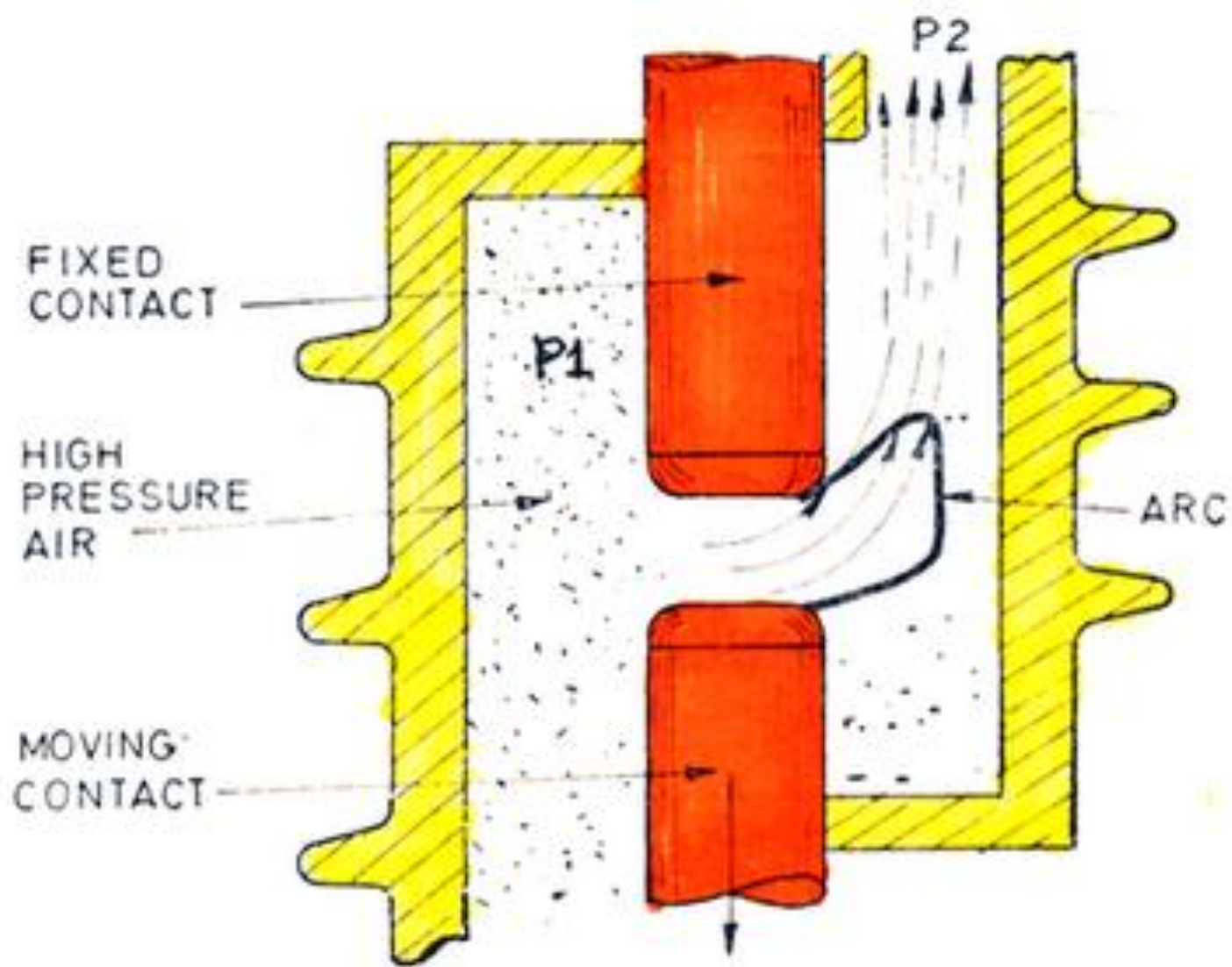
## 5.2.3 Principle of Arc Quenching in Air Blast Circuit Breaker

- The air blast circuit breaker needs an auxiliary compressed air system which supplies air to the air receiver of the breaker. For opening operation, the air is admitted in the arc extinction chamber. **It pushes away the moving contacts against spring pressure.** In doing so, the contacts are separated and the air blast takes away the ionized gases along with it and assists arc extinction. **After few cycles the arc is extinguished by the air blast and the arc extinction chamber is filled with high pressure air (30kgf/cm<sup>2</sup> ).** The high pressure air has higher dielectric strength than that of atmospheric pressure. Hence a small contact gap of a few centimetre is enough.

- **The flow of air around contacts is guided by the nozzle shaped contacts. It may be axial, across or a suitable combination { Fig. 10(a), (b)}.**



(a) Axial flow.



(b) Cross flow in ABCB—(Not used).

Figure 10 Flow of air around contacts in air blast circuit breaker

- In the axial blast type air flow Fig. 10 (a) the flow air is longitudinal, along the arc. In axial blast type air flow, the air flows from high pressure reservoir to the atmospheric pressure through a convergent divergent nozzle. The difference in pressure and the design of nozzle is such that as the air expands into the low pressure zone, it attains almost supersonic velocity. The mass flow of air through the nozzle is governed by the parameters like pressure ratio, area of throat, nozzle throat diameter and is influenced by the diameter of the arc itself.

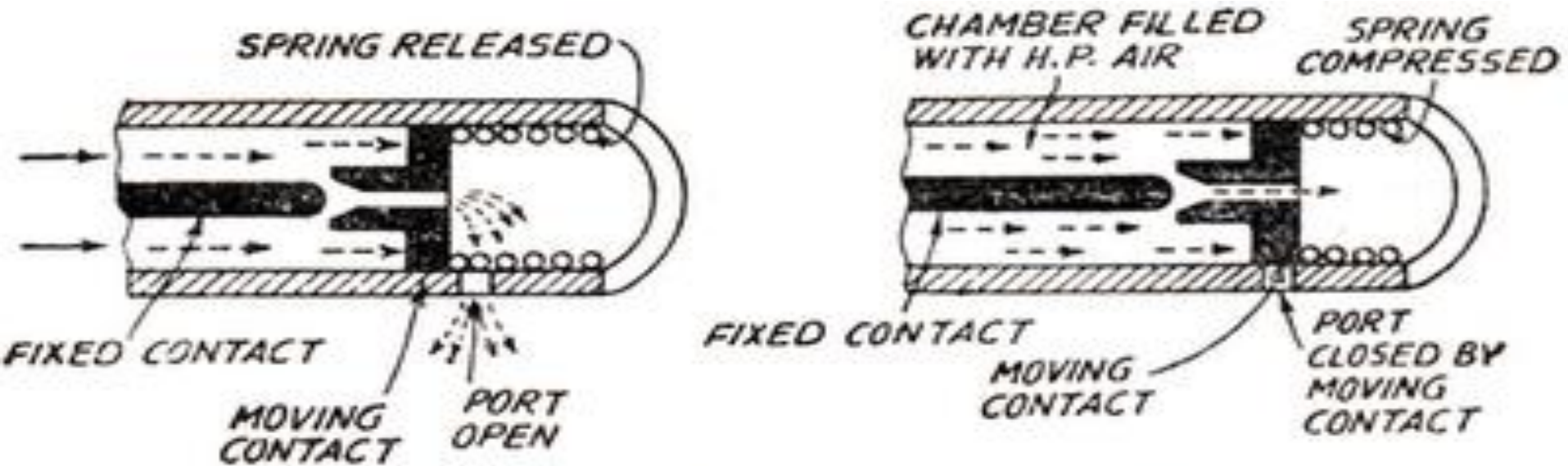
- The air flowing at high speed axially along the arc causes removal of heat from the periphery of the arc and the diameter of the arc reduces to a low value at current zero. At this instant the arc is interrupted and the contact space is flushed with fresh air flowing through the nozzle.
- The flow of fresh air through the contact space ensures removal of hot gases and rapid building up of the dielectric strength.



- The principle of cross blast illustrated in Fig. 10 (b) is used only in the circuit breaker of relatively low rating such as 12 KV, 500 MVA.
- The experience has shown that in the cross blast flow, the air flows around the arc and the diameter of arc is likely to remain stable for higher values of current.
- During the period of arc extinction, the air continues to flow through the nozzle to the atmosphere. The mass flow rate can be increased by increasing the pressure system. the increase in the mass flow results in increased breaking capacity.

- After the brief duration of air flow, the interrupter is filled with high pressure air. The dielectric strength of air increases with pressure. Hence the fresh high pressure air in the contact space is capable of withstanding the transient recovery voltage.
- After the arc extinction the interrupter chamber is filled with high pressure air. For closing operation, the air from this chamber is let out to the atmosphere. Thereby the pressure on the moving contacts from one side is reduced and the moving contacts close rapidly by the spring pressure (Fig. 11).

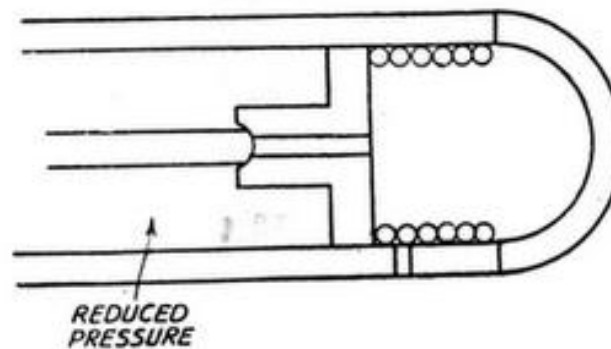
# Figure 11 Principle of Operation in ABCB



Opening by air pressure against spring pressure. Air is going out from the port.

Contacts open, port closed, the chamber filled with high pressure air.

(a) Sequence of operation in ABCB.



(b) Contact close by spring pressure against reduced air pressure.

# 5.2.4 Merits and Demerits of Air Blast Circuit Breaker

## **Merits :**

- Can be used at high pressure.
- Reliable operation due to external source of extinguishing energy.
- Free from decomposition.
- Clean, non-inflammable.
- Air is freely available everywhere.
- Fresh medium is used every time. Hence the breaker can be repeatedly operated, if designed for such duty.
- At high pressure the small contact travel is enough.
- The same serves purpose of moving the contact and arc extinction

- High speed of operation. The compressed air moves very fast and brings about the opening operation. The arcing time is also short. Hence total breaking time is short operation mechanism of air blast circuit breaker are pneumatic. The arcing time is almost exactly 0.01 second, i.e  $1/2$  cycle plus another  $1/2$  cycle for operation the contacts. Hence breaker speed of the order of 2 cycles can be achieved. This makes the circuit breaker suitable for important lines because high speed opening and auto-reclosure can improve system stability.
- Rapid auto-reclosure The circuit breaker can be given rapid auto-reclosure feature. The manufacturer gives such a provision at additional cost. The ABCB is easy to reclose because the reclosure is by spring pressure against reduced air pressure.

- Clean service. No need of maintenance as of oil
- Unit type construction gives advantage in design, manufacturer and testing
- Very high breaking capacities and service voltage can be obtained by connection more number of units in series. Hence for all extra high voltage and high breaking capacities of today air-blast circuit breakers are used, e.g. 420 KV, 63.5 KA, 2 cycles
- Suitability for repeated operation, The fresh air is used every time. Hence the breaker can be used for repeated operation if designed for duty. This is not the case with oil circuit breaker.

## Demerits :

- Complex design of arc extinction chambers and operating mechanisms, problems for switching over voltages are reduced by reclosing resistors.
- Auxiliary high pressure air system is necessary. The cost can be justified if there several breakers in the switching yard. For a single breakers the cost of auxiliary compressed air system would be too high.

- 5.2.5 Maintenance aspects
- Maintenance of ABCB is comparatively easier than that of tank type oil circuit breaker and minimum oil circuit breaker. This is because there is no oil, which needs regular testing and purification. Secondly, the units can be easily disassembled, checked and reassembled. The assembly of various units is similar and easy. The operating mechanism can be easily dismantled and reassembled.
- The major problem in air blast installation is the leakage from compressed air system and from the pipe connection. The leakage takes place from the threaded joints or from mating parts joined by means of nut-bolts



## 5.3 Bulk Oil and Minimum Oil Circuit Breaker

- Such circuit breakers utilize dielectric oil (transformer oil) for arc extinction. In bulk oil circuit breakers, the contacts are separated inside a steel filled with dielectric oil. In minimum oil circuit breakers, the contacts are separated in an insulation housing (interrupter) filled with dielectric oil.

- The oil in oil circuit breakers( OCBs) serves two purpose. It insulates between the phases and between the phases and the ground, and it provides the medium for the extinguishing of the arc. When electric arc is drawn under oil, the arc vaporizes the oil and creates a large bubble that surround the arc. The gas inside the bubble is around 80% hydrogen, which impairs ionization. The decomposition of oil into gas requires energy that comes from the heat generated by the arc. The oil surrounding the bubble conducts the heat away from the arc and thus also contributes to deionization of the arc.

- Main disadvantage of the oil circuit breakers is the flammability of the oil, and the maintenance necessary to keep the oil in good condition ) i.e. changing and purifying the oil).
- Bulk oil circuit breaker (tank type circuit breakers) are becoming obsolete and have been described here in brief.
- **Minimum oil circuit breaker has the following demerits:**
  1. Short contact life.
  2. frequent maintenance.
  3. Possibility of explosion.
  4. Larger arcing time for small current.
  5. Prone to re-strike
  6. They are being superseded by SF6 circuit breakers in all ranges.

- 5.3.1 Tank type or Bulk Oil Circuit Breaker (now obsolete)
- Bulk oil circuit breakers are enclosed in metal-grounded weatherproof tanks that are referred to as dead tanks. **The tank type circuit breakers had 3 separate tanks for 72.5 KV and above (Fig. 12a). For 36 KV and below, single tank construction, phase barriers were provided between phase.**
- The contact separation takes place in steel tanks filled with oil. The gases formed, due to the heat of the arc, expand and set the turbulent flow in the oil. The arc was drawn directly inside of the container tank without any additional arc extinguishing but the one provided by the gas bubble surrounding the arc. Plain break breakers were superseded by arc controlled oil breakers.

- To assist arc extinction process, arc control devices were fitted to the contact assembly. These were semi-enclosed chamber of dielectric materials. The purpose of the arc control devices is to improve operating capacity, speed up the extinction of arc, and decrease pressure on the tank. The performance of oil circuit breaker depended on the effectiveness of the arc control devices.



Prof. Dr. Sayed A. Ward (a) 115 KV circuit breaker C.Bs and Substations 4th Year Elec. Power Eng.



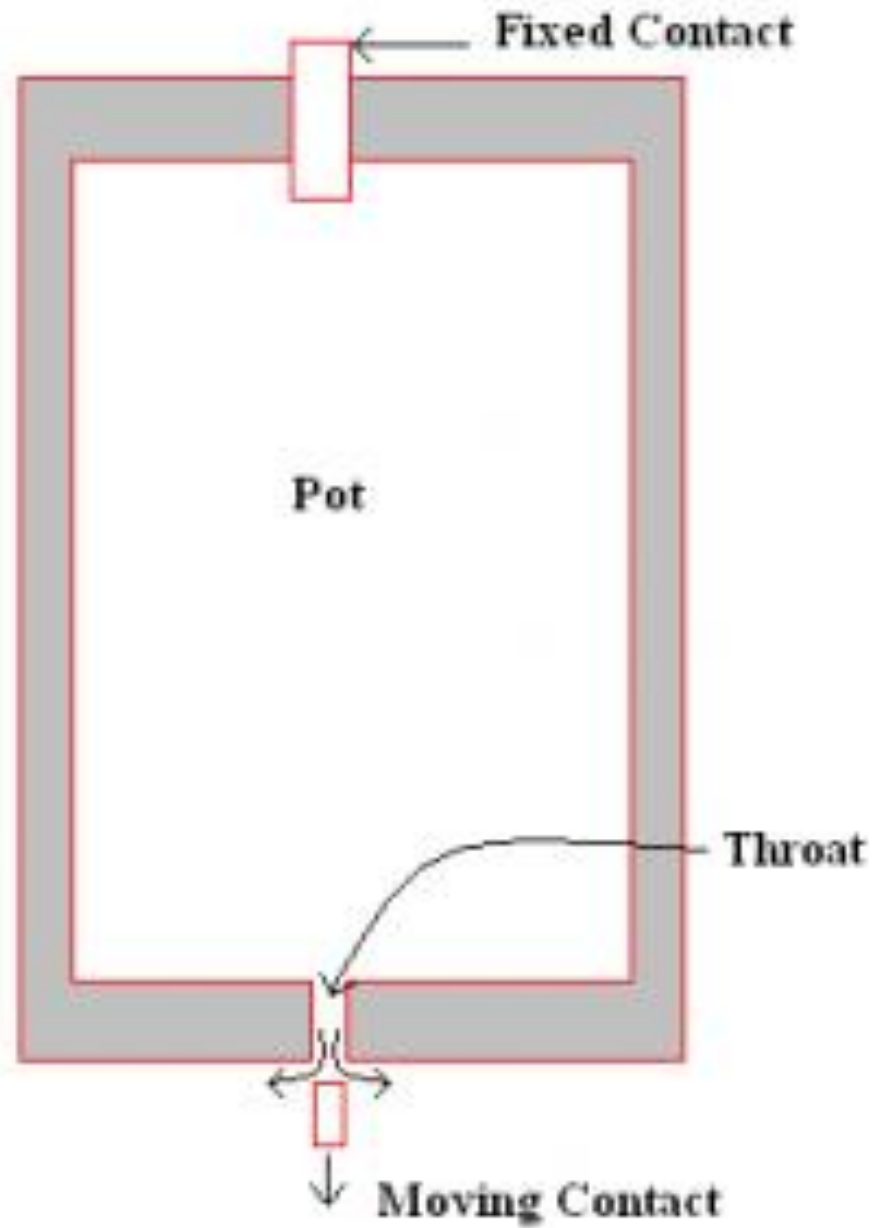
( b ) 66 KV circuit breaker

- The breakers incorporate arc control are called arc control circuit breakers.  
These are two types of such breakers:
- **Self blast oil circuit breakers** - in which arc control is provided by internal means i.e. are itself facilitates its own extinction efficiency.
- **Forced blast oil circuit breakers** - in which arc control is provided by mechanical means external to the circuit breaker.



- **Self blast oil circuit breaker –**
- in this type of breakers, the gases produced during arching are confined to a small volume by the use of an insulating rigid pressure chamber or explosion pot surrounding the contacts. The space available for the arc gases is restricted by the chamber so a very high pressure is developed to force the oil and gas through or around the arc to extinguish it. The magnitude of the pressure depends upon the value of fault current to be interrupted. The arc itself generates the pressure so such breakers are also called self generated pressure oil circuit breakers.

- The pressure chamber is relatively cheap and gives reduced final arc extinction gap length and arcing time as against the plain oil breaker. Different types of explosion pots are described below:
- **Plain explosion pot** - It is a rigid cylinder of insulating material and encloses the fixed and moving contacts as shown in Fig. 13. The moving contact is a cylindrical rod passing through a restricted opening called throat at the bottom. When fault occurs the contacts get separated and arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and gas through and around the arc to extinguish it.



Prof. Dr. Sayed A. Ward **Figure `13 Plain explosion pot principle** G.Bs and Substations 4th year elec. Power Eng.

- If the arc extinction will not take place when the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because, emergence of moving contact will be followed by violent rush of gas and oil through the throat production rapid extinction.
- Limitation of this type of pot is that it cannot be used for very low or very high fault currents. With low fault currents the pressure developed is small, thereby increasing the arcing time. And with high fault currents, the gas is produced so rapidly that the pot may burst due to high pressure. So this pot is used on moderate short circuit currents only when rate of gas evolution is moderate.

- **Cross jet explosion pot** - Figure 14 shows the cross jet pot which is made of insulating material and has channels on one side that acts as arc splitters. The arc splitter help in increasing the arc length, thus facilitating arc extinction. when fault occurs, the moving contact of the circuit breaker begins to separate and arc is struck in the top of the pot. The gas generated by the arc exerts pressure on the oil in the back passage. When the moving contact uncovers the arc splitter ducts, fresh oil is forced across the arc path. The arc is therefore driven sideways into the arc splitters, which increase the arc length, causing arc extinction.
- The cross jet explosion pot is used for interrupting heavy fault currents. For low fault currents the gas pressure is small and consequently the pot does not give a satisfactory operation.

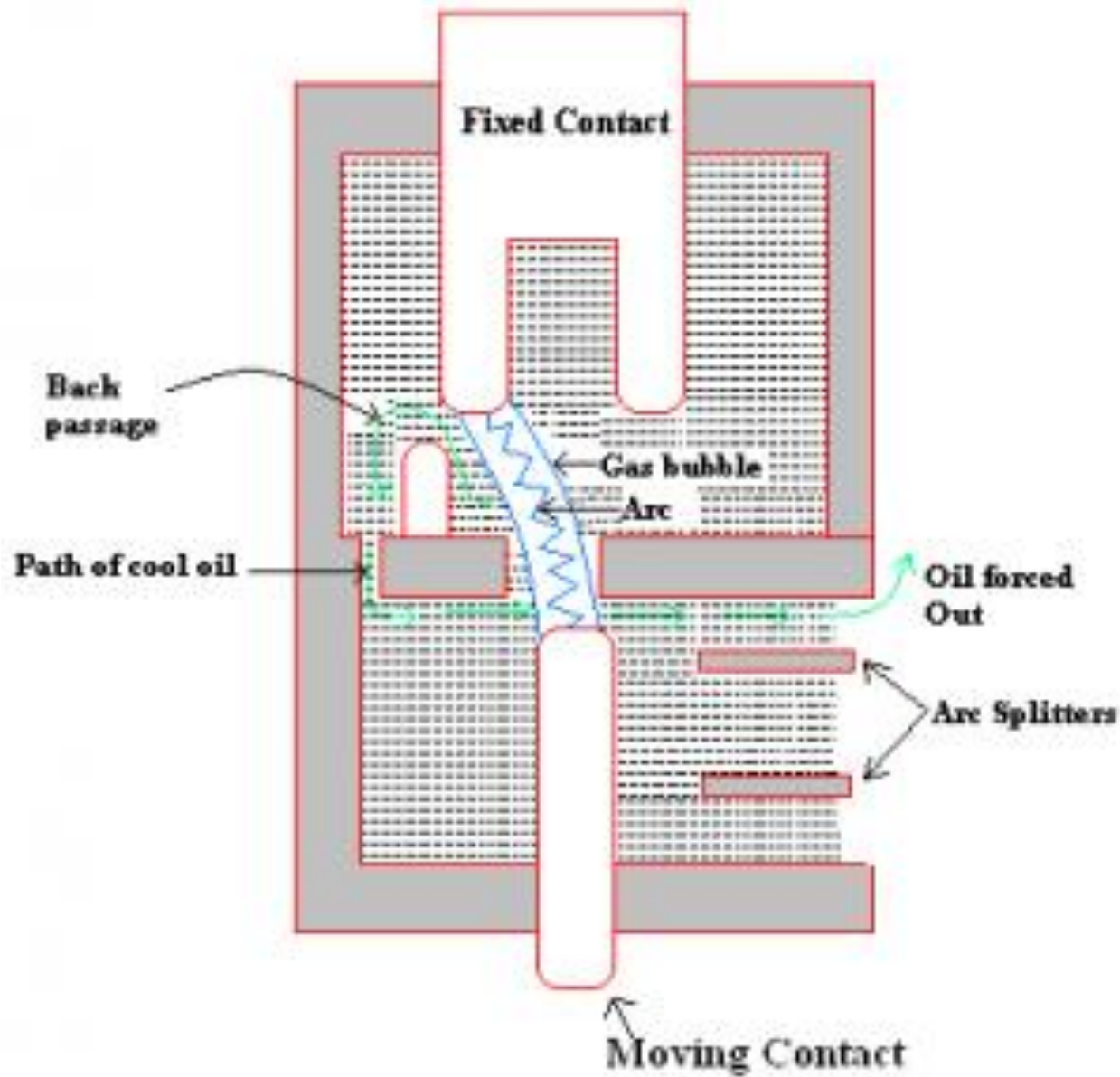
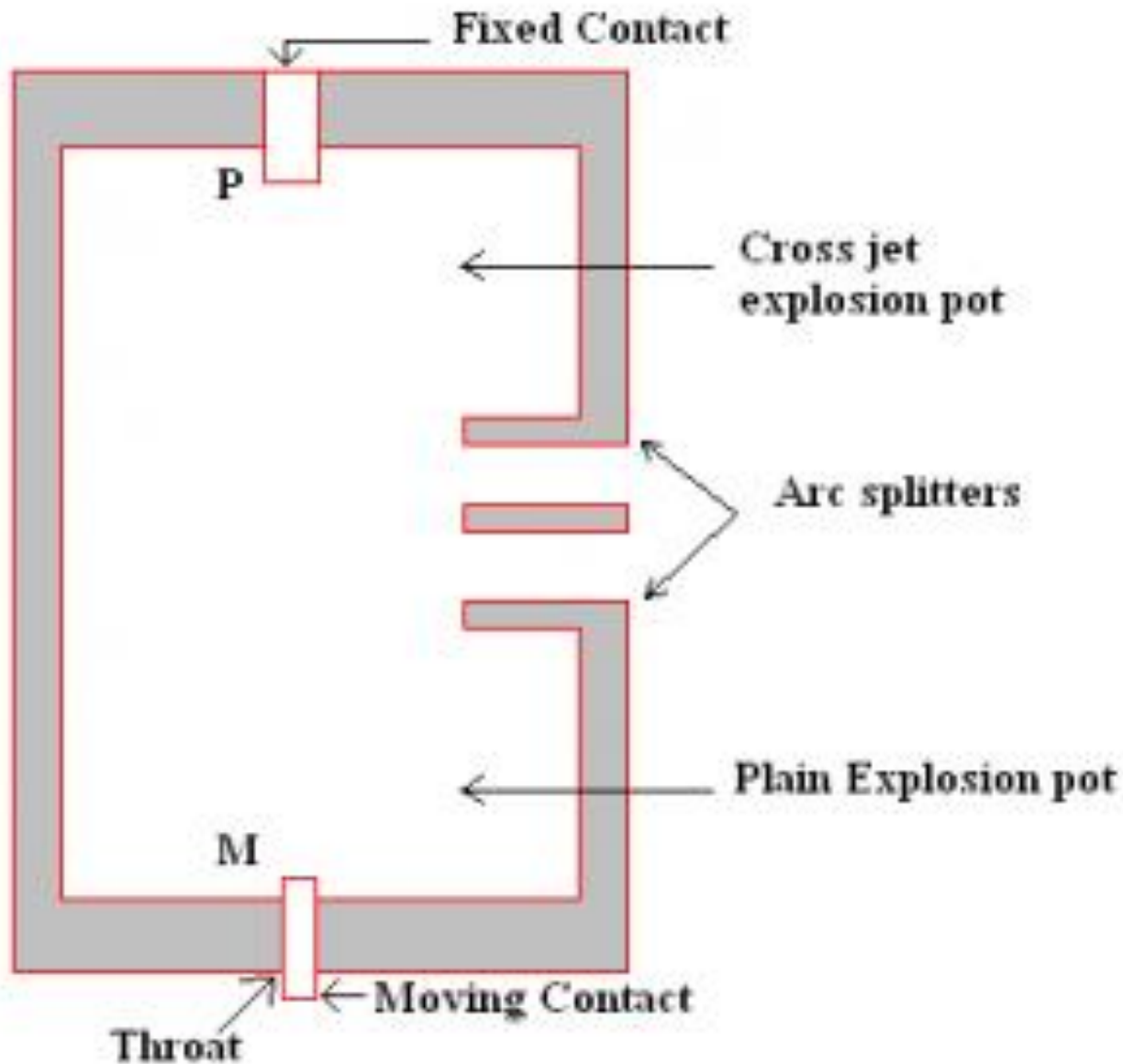


Figure 14 Principle of cross jet explosion pot <sup>126</sup>

- **Self compensated explosion pot** - This pot is a combination of plain explosion pot and cross jet explosion pot. So it can interrupt low as well as heavy short circuit currents. Figure 15 shows the itself compensated explosion pot.

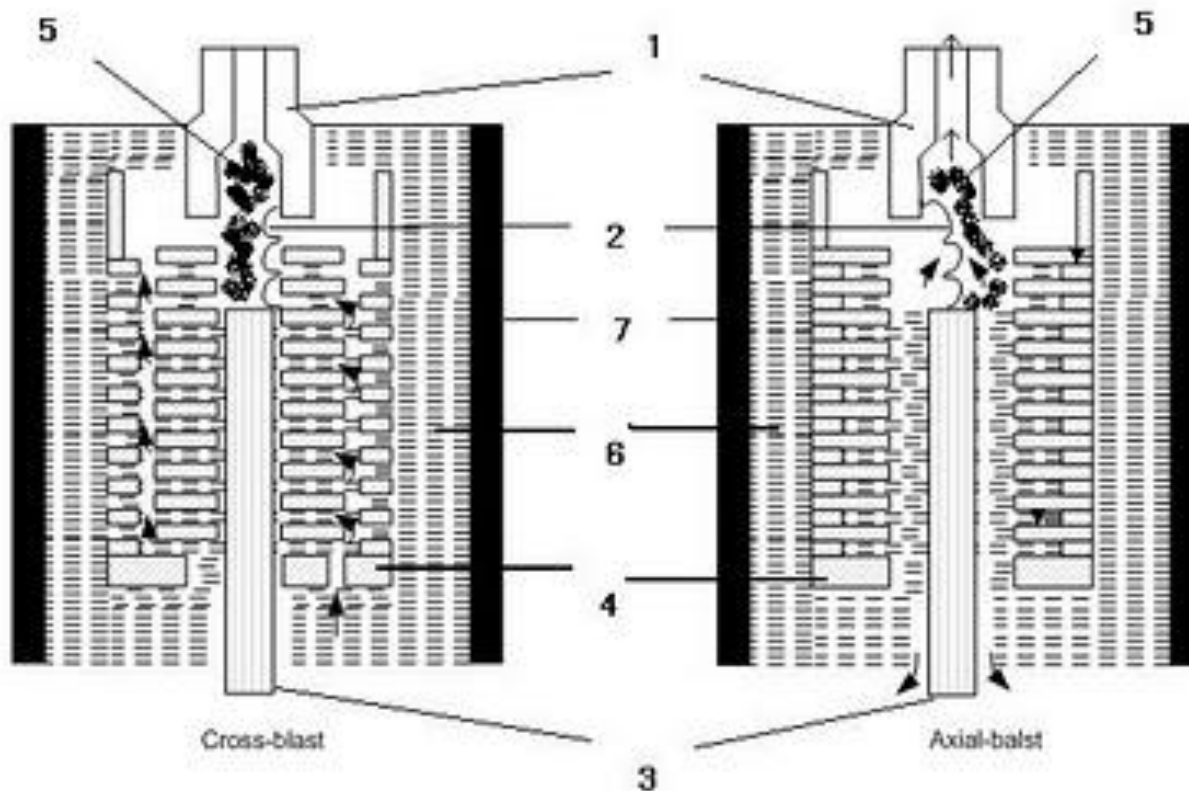


**Figure 15** self compensated explosion pot



# Forced Blast Oil Circuit Breaker

- In this type of circuit breaker there is a piston attached to a moving contact. When fault occurs the moving contact moves and hence the piston associated with it also moves producing pressure inside the oil chamber. So the oil gets movement or turbulates and quenching the arc.
- The arc control devices can be classified into two groups: cross-blast and axial blast interrupters (Fig. 16).



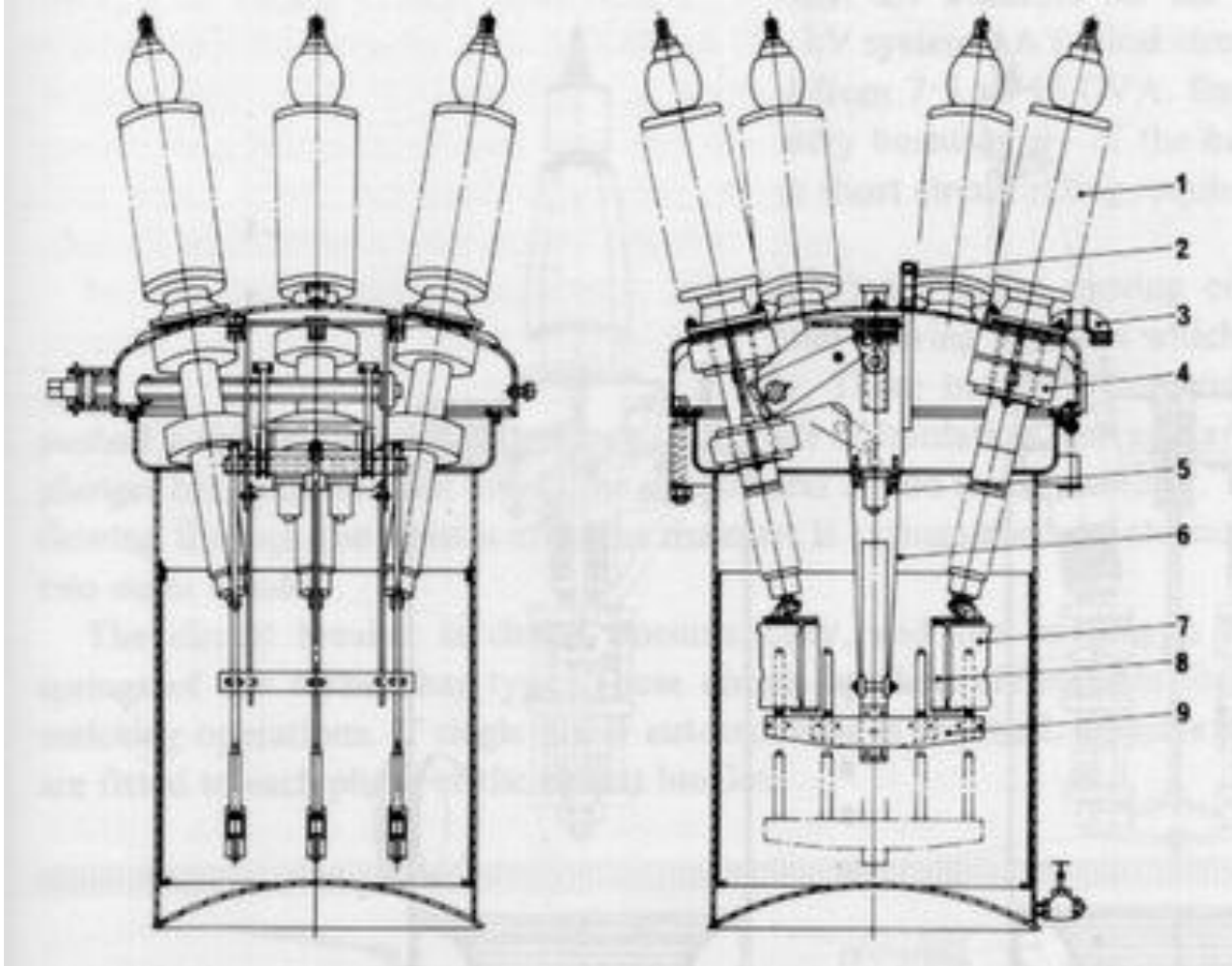
**Figure contents:**

- 1. Fixed contact assembly**
- 2. Arc**
- 3. Moving contact with tungsten-copper tip**
- 4. Fiber reinforced tube**
- 5. Gas evolved by decomposition of oil**
- 6. Dielectric oil**
- 7. Outer enclosure (Porcelain or Fiber Reinforced Epoxy )**

**Figure 16 Classification of arc control devices**

- **In cross blast interrupters**, the arc is drawn in front several lateral vents. The gas formed by the arc causes high pressure inside the arc control device. The arc is forced into the lateral vents in the pot, which increases the length of the arc and shortens the interruption time. **The axial blast interrupters use similar principle as the cross blast interrupters.** However, the axial design has a better dispersion of the gas from the interrupter.

- Figure 17 illustrates a typical 69 KV breaker of 2500 MVA breaking capacity. All three phases are installed in the same tank. The tank is made of steel and is grounded. This type of breaker arrangement is called the dead tank construction. The moving contact of each phase of the circuit breaker is mounted on a lift rod of insulating material. There are two breaks per phase during the breaker opening. The arc control pots are fitted over the fixed contacts. Resistors parallel to the breaker contacts may be installed alongside the arc control pots. It is customary and convenient for this type of breakers to mount current transformers in the breaker bushings.

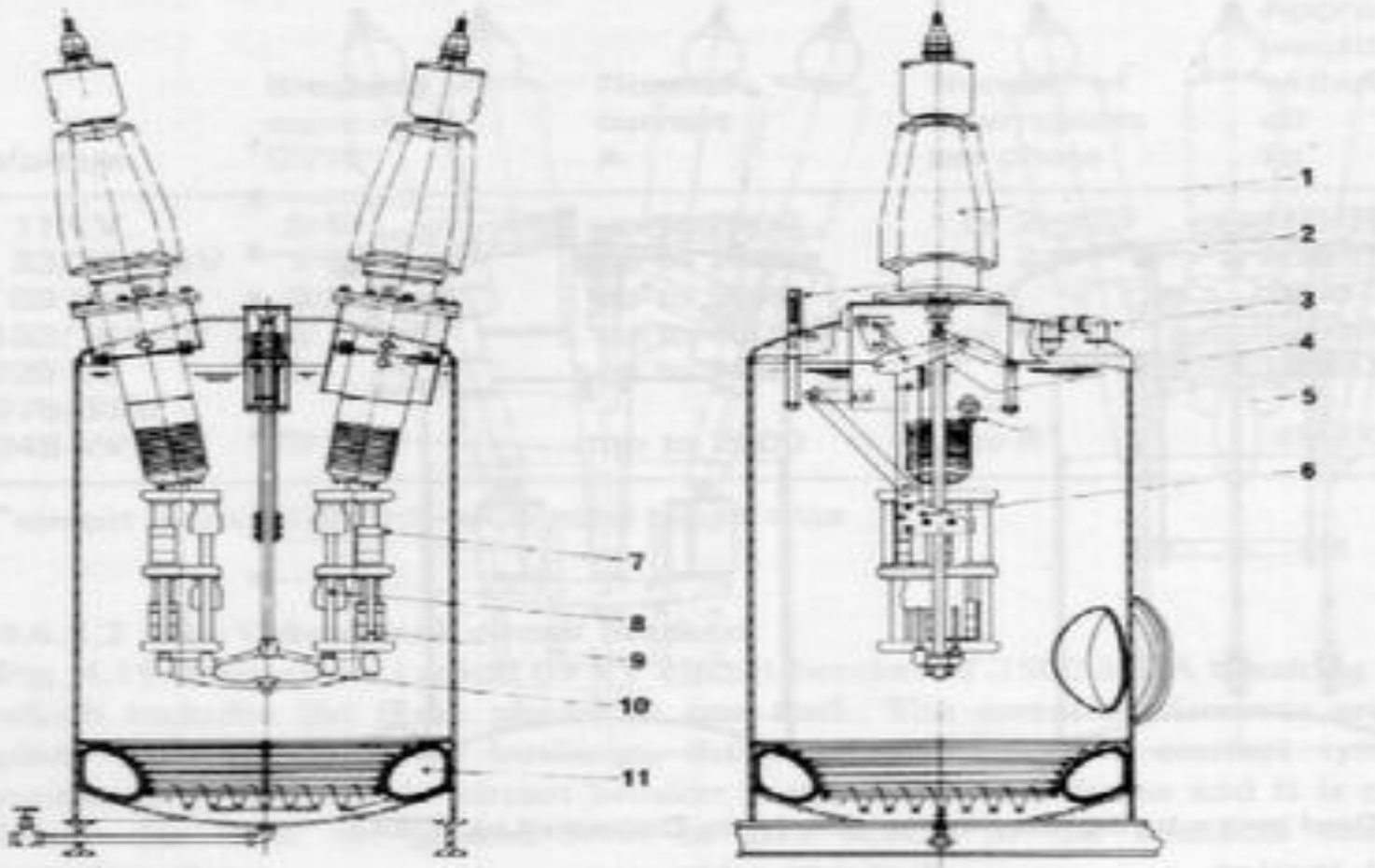


**Figure contents :**

- |          |                            |          |                            |          |                      |
|----------|----------------------------|----------|----------------------------|----------|----------------------|
| <b>1</b> | <b>bushing</b>             | <b>2</b> | <b>oil level indicator</b> | <b>3</b> | <b>vent</b>          |
| <b>4</b> | <b>current transformer</b> | <b>5</b> | <b>dashpot</b>             | <b>6</b> | <b>plunger guide</b> |
| <b>7</b> | <b>arc control device</b>  | <b>8</b> | <b>resistor</b>            | <b>9</b> | <b>plunger bar</b>   |

**Fig. 17** dead tank oil circuit breaker

- The practical limit for the bulk oil breakers is 275 KV. Figure 18 shows 220 KV one phase dead tank circuit breaker.



**Figure content ;**

- |          |                            |           |                         |
|----------|----------------------------|-----------|-------------------------|
| <b>1</b> | <b>bushing</b>             | <b>7</b>  | <b>arc control unit</b> |
| <b>2</b> | <b>oil level indicator</b> | <b>8</b>  | <b>parallel contact</b> |
| <b>3</b> | <b>vent</b>                | <b>9</b>  | <b>resistor</b>         |
| <b>4</b> | <b>linear linkage</b>      | <b>10</b> | <b>plunger bar</b>      |
| <b>5</b> | <b>dashpot</b>             | <b>11</b> | <b>impulse cushion</b>  |
| <b>6</b> | <b>guide block</b>         |           |                         |

**Figure 18** Single phase tank oil circuit breaker

- The oil circuit breakers are usually installed on concrete foundations at the ground level. During interruption of heavy fault currents the breakers tend to move. To minimize the damage to the breakers, breakers with very high interrupting capacity have an impulse cushion is provided at the bottom of the breakers. The cushion filled with an inert gas, for example nitrogen.
- Figure 19 illustrates the tank type oil circuit breaker, in open position, with the arc is not yet extinguished



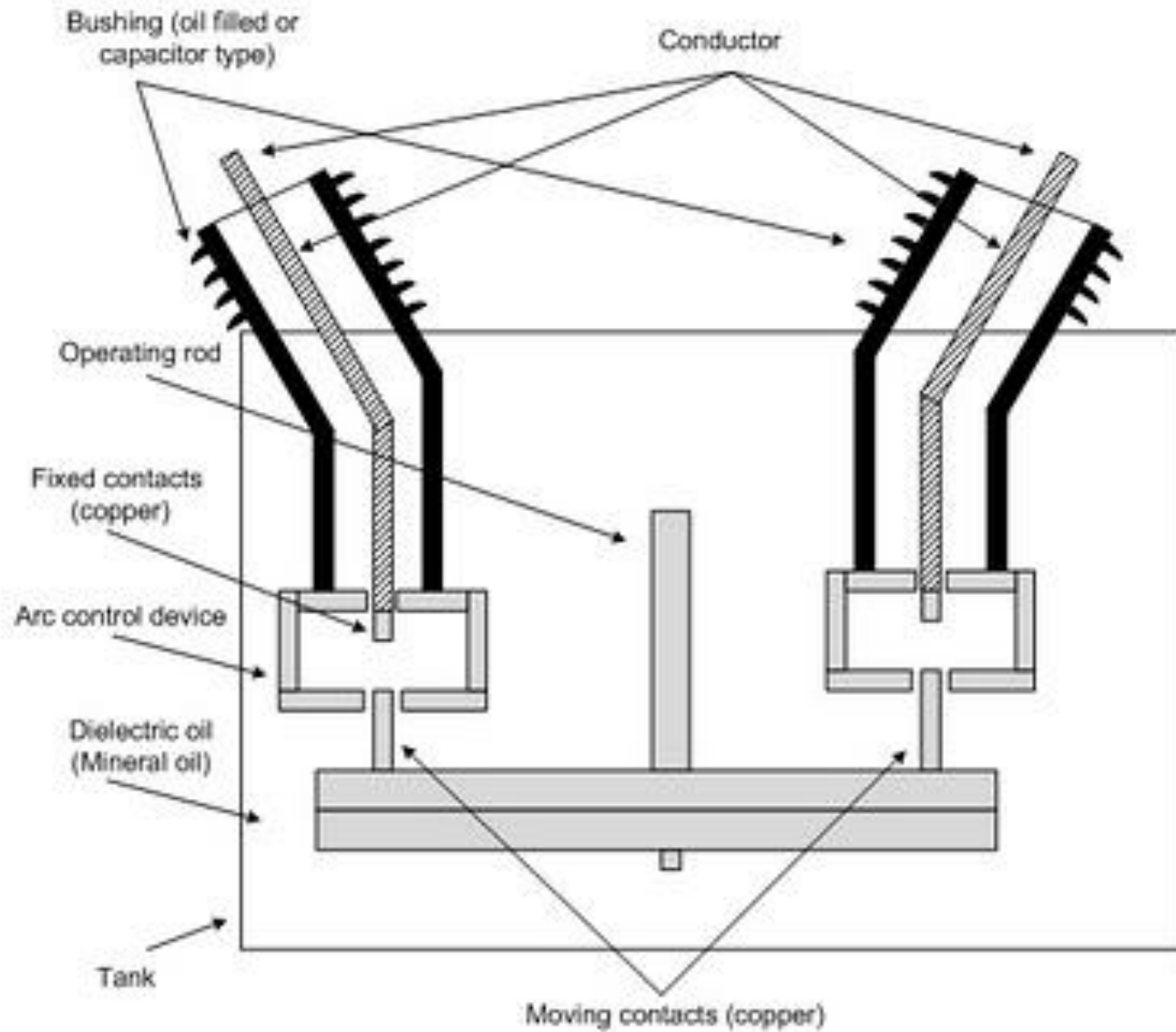


Figure 19 Schematic diagram of bulk oil circuit breaker

- The major disadvantages of tank type C.B. are ;
  1. Large quantity of oil is necessary in oil circuit breakers though only a small quantity is necessary for arc extinction.
  2. The entire oil in the tank is likely to get deteriorated due to sludge formation in proximity of the arc. Then the entire oil needs replacement.
  3. The tanks are too big, at 36 KV and above, and the tank type oil circuit breaker loses its simplicity,
- **The above causes led to the development of minimum oil circuit breakers.** As the name itself signifies, the minimum oil circuit breaker requires less oil. The arc extinction medium is dielectric oil, the same as that used in tank type circuit breakers. **There is no steel tank but the arc extinction takes place in a porcelain containers.**

# 5.4 Sulphur Hexafluoride (SF6) Circuit Breaker and SF6 Insulated Metalclad switchgear

## 5.4.1 Introduction

- Sulphur hexafluoride (SF6) is an inert, heavy gas having good dielectric and arc extinguishing properties. The dielectric strength of the gas increases with pressure and is more than that of dielectric oil at pressure of 3 kgf/cm<sup>2</sup> . This gas is now being very widely used in electrical equipment like high voltage metal enclosed cables; high voltage metal clad switchgear, capacitors, circuit breakers, current transformers, bushings, etc. This gas liquefies at certain low temperatures, the liquefaction temperature increases with pressure. This gas is commercially manufactured in many countries and is now being extensively used by electrical industry in Europe, U.S.A. and Japan.

- Several types of SF6 circuit breakers have been developed by various manufacturers in the world, for rated voltage from 3.6 to 760 KV. However, at present they are generally preferred for voltages above 72.5 KV.
- SF6 gas insulated metal clad switchgear comprises factory assembled metal clad, substation equipment like circuit breakers, isolators, earthing switches, bus bars, etc. These are filled with SF6 gas . Such sub-stations are compact and are being favoured in densely populated urban areas.

- Sulphur hexafluoride gas is prepared by burning coarsely crushed roll sulphur in the fluorine gas, in a steel box, provided with staggered horizontal shelves, each bearing about 4 kg of sulphur. The steel box is made gas-tight. The gas thus obtained contains other fluoride such as  $S_2F_{10}$ ,  $SF_4$  and must be purified further.  $SF_6$  gas is generally supplied by chemical firms. The cost of gas is low if manufactured on a large scale.
- The gas is transported in liquid form in cylinders. Before filling the gas, the circuit breaker is evacuated to the pressure of about 4 mm of mercury so as to remove the moisture and air. The gas is then filled in the circuit breaker. The gas can be reclaimed by the gas-handling unit

- **There are two types of SF6 circuit breakers:**
  1. **Single pressure puffer type SF6 circuit**
- In which the entire circuit breaker is filled with SF6 gas at single pressure ( 4 to 6 kgf/cm<sup>2</sup> ) . The pressure and gas flow, required for arc extinction, is obtained by piston action.
- 2. **Double pressure type SF6 circuit breaker**
- In which the gas from high pressure system is released into low pressure system over the arc during the arc quenching process. This type has been superseded by puffer type.

## 5.4.2 Properties of SF6 Gas

- Sulphur hexafluoride (SF6) gas has good dielectric and arc extinguishing properties. The dielectric strength of the gas increase with pressure and is more than that of the dielectric oil at high pressures. SF6 is now very widely used in electrical equipments like high voltage metal enclosed cables, high voltage metal clad switchgear, capacitors, circuit breakers, current transformers, high voltage bushing, etc.
- Sulphur hexafluoride gas is of low cost if manufactured on a large scale. It is transported in liquid from cylinders. Before filling the gas, the circuit breaker is evacuated to the pressure of about 4mm of mercury so as to remove the moisture and air. The gas is then filled in the C.B.

## 5.4.2.1 Physical properties of SF6 gas

- Colorless.
- Odorless.
- Nontoxic. Pure SF6 gas is not harmful to health. However, impure SF6 gas contains toxic impurities.
- Inflammable.
- Stat: gas at normal temperature and pressure.
- Density : heavy gas with density 5 times that of air at 20 ° C and atmospheric pressure.
- - **Liquefaction of SF6 Gas**



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- - **Liquefaction of SF6 Gas**

## • **Liquefaction of SF6 Gas**

- The gas starts liquefying at certain low temperatures. The temperature of liquefaction depends on pressure. At 15 kgf/cm<sup>2</sup> the gas starts liquefying at 10 ° C . Hence this gas is not suitable for pressure above 15 kgf/cm<sup>2</sup>
- The temperature at which the SF6 gas changes to liquid state depends on the pressure. With higher pressure, the temperature increases. To avoid the liquefaction of SF6 gas, the temperature of SF6 should be maintained above certain value. For atmospheric pressure, SF6 gas starts liquefying at a temperature of about 10 ° C. Hence thermostatically controlled heaters are provided, which maintain the gas temperature above about 16 ° C in case of high pressure system.

- **Heat Transferability**

- The heat transferability of SF6 gas is 2 to 2.5 times that of air at same pressure. Hence for the equal conductor size, the current carrying capacity is relatively more.

- - **Enthalpy**

- Heat content property at temperature below  $6000^{\circ}$  K is much higher than nitrogen. This assists cooling of arc space after current zero, due to continuous removal of heat from the contact space by the surrounding gas.

- **Low arc time constant**
- The time constant of the medium is defined as "the time between current zero and the instant the conductance of contact space reaches zero value". Due to the electro negativity of SF6 gas the arc time constant of SF6 gas is very low and the rate of dielectric strength is high. Hence SF6 circuit breakers are suitable for switching condition involving high rate of rise of TRV.

## • 5.4.2.2 Chemical properties of SF6 Gas

1. Stable up to  $500^{\circ}\text{C}$ .
2. Inert. The chemical inertness of this gas is advantageous in switchgear. The life of metallic part, contacts is longer in SF6 gas. The components do not get oxidized or deteriorated. Hence the maintenance requirements are reduced. Moisture is very harmful to the properties of the gas. In the presence of moisture, hydrogen fluoride is formed during arcing which can attack the metallic and insulating parts in the circuit breaker.

3. Electronegative gas.
4. Does not react with structural material up to  $500^{\circ}\text{C}$ .
5. Products of decomposition. During arc extinction process SF<sub>6</sub> is broken down to some extent into SF<sub>4</sub>, SF<sub>2</sub>. The products of decomposition recombine upon cooling to form the original gas. The remainder is removed by filters containing activated alumina ( AL<sub>2</sub>O<sub>3</sub>) Loss factor is small. The products of decomposition are toxic and attack certain structural materials.
6. The metallic fluorides are good dielectric materials hence are safe for electrical equipment.
7. Moisture content in the gas, due to influx from outside, present a various problems in SF<sub>6</sub> circuit breakers. Several failures have been reported recently due to this cause.

### • 5.4.2.3 Dielectric properties of SF6 Gas

- Dielectric strength of SF6 gas atmospheric pressure is 2.35 times that of air, it is 30% less than of dielectric oil used in oil circuit breakers.
- At higher pressure the dielectric strength of the gas increases. At pressure about 3 kgf/cm<sup>2</sup> the dielectric strength of SF6 gas is more than that of dielectric oil. This property permits smaller clearance and small size of equipments for the same KV.
- The breakdown voltage in SF6 gas depends on several aspects such as electrode configuration, roughness of electrodes, distribution of electric field, vicinity of insulating supports, moisture, wave shape etc. Other parameters remaining constant, the breakdown voltage in SF6 increases with pressure. The gas follows paschen's law which states that "in uniformly distributed electric field, the breakdown voltage ( $V_b$ ) in a gas is directly proportional to the product of gas pressure (p) and electrode gap (d)"

$$V_b \propto pd$$

- With the non uniform field, the breakdown voltage versus pressure curve does not follow the paschent's law strictly. The breakdown voltage increases with pressure. However after about 2.5 kgf/cm<sup>2</sup> it starts reducing and then rises again.  
The pressure at which the breakdown voltage starts reducing is called 'Critical pressure'. The dielectric strength at pressure between 2-3 kgf/cm<sup>2</sup> is high. Hence this pressure range preferred in SF6 insulated metal enclosed switchgear. However, in circuit breaker compartment, the pressure of the order of is kgf/cm<sup>2</sup> preferred for arc quenching process.



- Rough electrode surface reduces the breakdown voltage with rough surface the ionization starts earlier near the sharp points on conductors. Hence conductor surfaces should be smooth
- The conductor in SF6 insulating equipment are supported on epoxy or porcelain insulators. The flashover invariably takes place along the surface of the support insulators. The breakdown can occur at extremely low values if the insulators supports are covered by moisture and conducting dust. Hence the insulators should be extremely clean and should have anti-tracking properties.
- The breakdown is initiated at sharp edges of conducting parts and parts having maximum stress concentration. The limiting value of breakdown stress is of the order of  $20 P$  KV/cm for pure SF6 and  $P$  is pressure of gas in  $\text{kgf/cm}^2$  . Good stress distribution is very important in SF6 insulated equipment.

- The breakdown value depends on the wave-shape characterized by peak value, wave front, wave-tail, polarity in case of impulse wave. Voltage withstand value reduces with increase in steepness and increase in duration of the wave. Negative polarity is generally more severe than positive.
- SF6 gas maintain high dielectric strength even when diluted by air (Nitrogen). 30% SF6 + 70 % of air, by volume, has a dielectric strength twice that of air ( at the same pressure). Below 30% by volume, the dielectric strength reduces quickly.

## 5.4.3 Arc Extinction in SF6 Circuit Breaker

- High voltage circuit breaker with SF6 gas as the insulation and quenching medium have been in use throughout the world for more than 30 years. This gas is particularly suitable because of its high dielectric strength and thermal conductivity.
- The current interruption process in a high voltage circuit breaker is a complex matter due to simultaneous interaction of several phenomena. When the circuit breaker contacts separate, an electric arc will be established, and current will continue to flow through the arc. Interruption will take place at an instant when the alternating current reaches zero.

When a circuit breaker is tripped in order to interrupt a short circuit current, the contact parting can start anywhere in the current loop. After the contacts have parted mechanically, the current will flow between the contacts through an electric arc, which consists of a core of extremely hot gas with a temperature of 5,000 to 20,000 K. This column of gas is fully ionized (plasma) and has an electrical conductivity comparable to that of carbon. When the current approaches zero, the arc diameter will decrease with the cross section approximately proportional to the current. In the vicinity of zero passage of current, the gas has been cooled down to around 2,000 K and will no longer be ionized plasma, nor will it be electrically conducting.

- **Two physical requirements (regimes) are involved :**
- Thermal regime : The hot arc channel has to be cooled down to a temperature low enough that it ceases to be electrically conducting.
- Dielectric regime : After the arc extinction, the insulating medium between the contacts must withstand the rapidly increasing recovery voltage. This recovery voltage has a transient component (transient recovery voltage, TRV) caused by the system when current is interrupted.
- **If either of these two requirements is not met, the current will continue to flow for another half cycle, until the next current zero is reached. It is quite normal for a circuit breaker to interrupt the short circuit current at the second or even third current zero after contact separation.**

- Thermal regime

- The thermal regime is especially critical at short line fault interruption. The circuit parameters directly affecting this regime are the rate of decrease of the current to be interrupted ( $di/dt$ ) and the initial rate of rise of the transient recovery voltage ( $dv/dt$ ) immediately after current zero. The higher the values of either of these two parameters, the more severe the interruption is. A high value of ( $di/dt$ ) results a hot arc with a large amount of stored energy at current zero, which makes interruption more difficult. High values of ( $dv/dt$ ) will result in an increase of the energy to the post arc current.

- These exists a certain inertia in the electrical conductivity of the arc. When the current approaches zero, there is still a certain amount of electrical conductivity left in the arc path. This gives rise to what is called a "post-arc current". With amplitude up to a few A. Whether or not interruption is going to be successful is determined by a race between the cooling effect and the energy input in the arc path by the transient recovery voltage. When the scales of the energy balance tip in favour of the energy input the circuit breaker will fail thermally. The thermal interruption regime for SF6 circuit breakers corresponds to the period of time starting some  $\mu\text{s}$  before current zero, until extinguishing of the post arc current, a few  $\mu\text{s}$  after current zero.

## Dielectric regime

- When the circuit breaker has successfully passed the thermal regime, the transient recovery voltage (TRV) between the contacts rises rapidly and will reach a high value. For example, in a single unit 245 KV circuit breaker, the contact gap may be stressed by 400 KV or more 70 to 200  $\mu$ s after the current zero.
- In the dielectric regime the extinguishing/ isolating medium is longer electrically conducting, but it still has a much higher temperature than the ambient. This reduces the voltage withstand capacity of the contact gap. The stress on the circuit breaker depends on the rate of rise and the amplitude of the TRV.

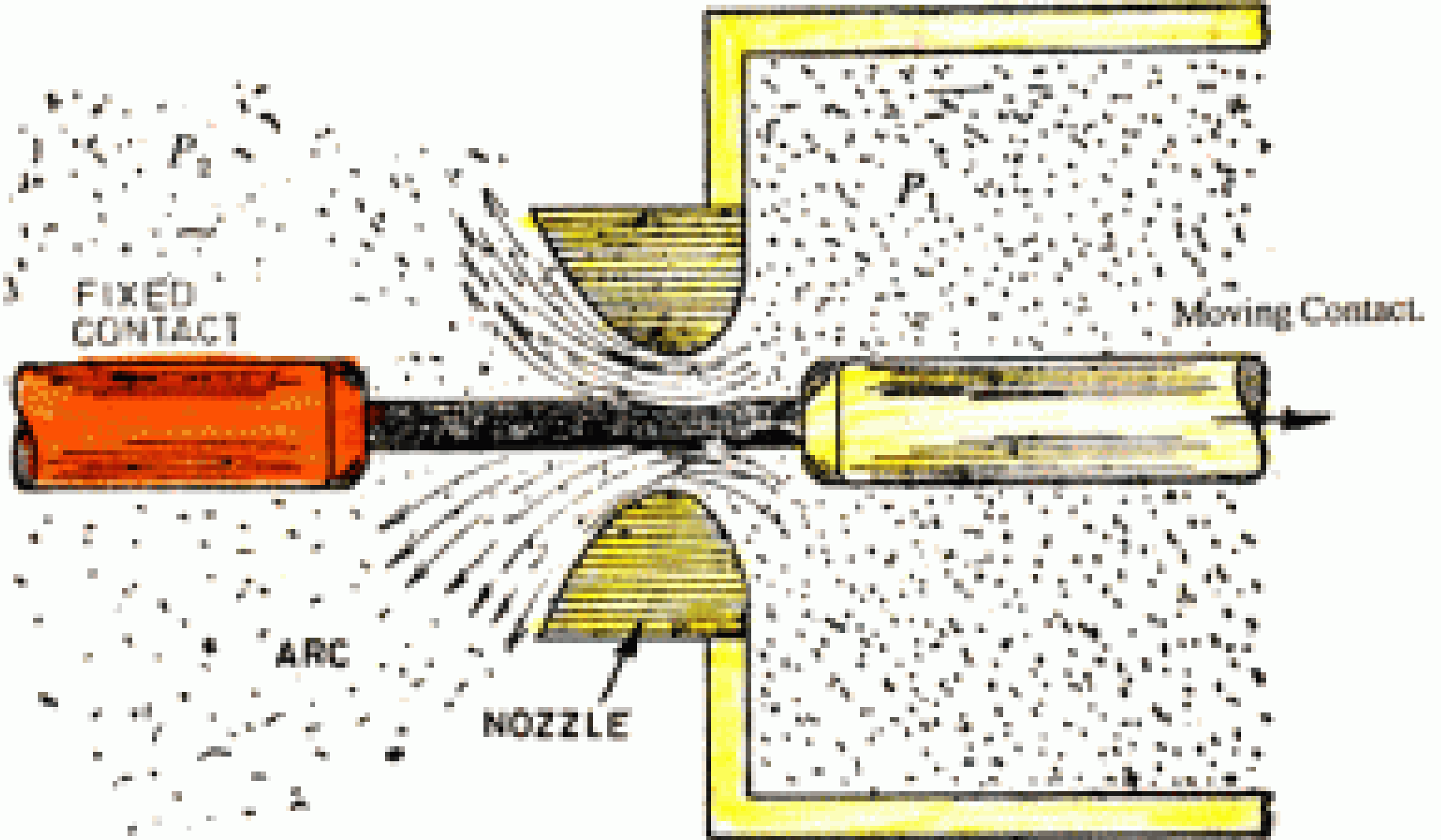


- The withstand capability of the contact gap must always be higher than the transient recovery voltage otherwise a dielectric re-ignition will occur (dielectric failure). This requires an extremely high dielectric withstand capability of the gas, which is still rather hot and therefore has low density.
- **The arc extinction process, in SF6 CB, is different from that in air blast CB.** During the arcing period, SF6 gas is blown axially along the arc. The gas removes from the arc by axial convection and radial dissipation. As a result, the arc diameter reduces during the decreasing mode of the current wave. The diameter becomes small during current zero **and the arc is extinguished.**

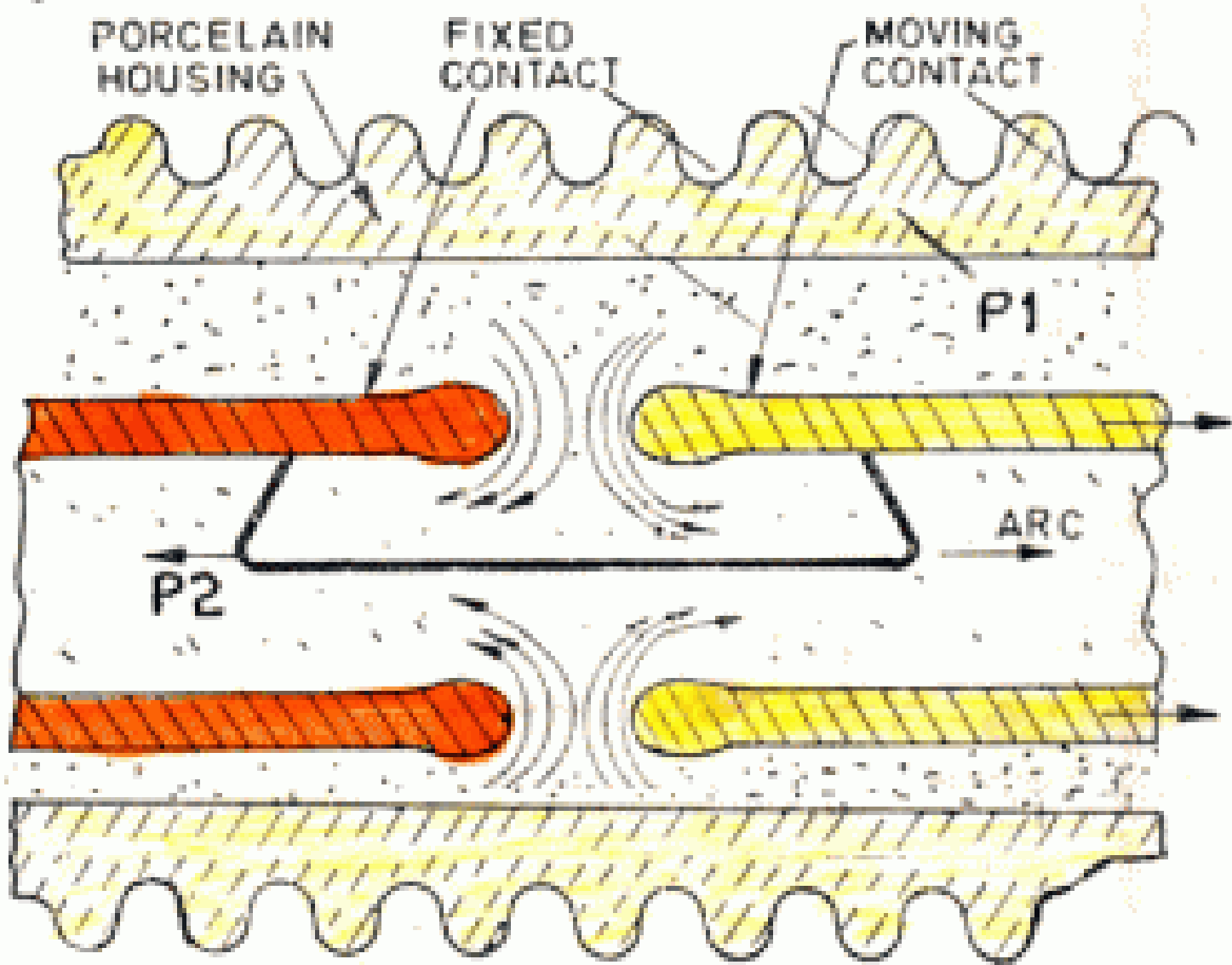
- Due to its electro negativity and low arc time constant, the SF6 gas regains its dielectric strength rapidly after the final current zero, the rate of rise of dielectric strength is very high and the time constant is very small.
- The arc extinguishing properties of SF6 gas was pointed out in 1953. The research pointed out that SF6 is a remarkable medium for arc extinction. The arc extinguishing properties are improved by moderate rates of forced gas flow through the arc space.
- Plain break contacts drawn apart, (AC arcs), in SF6 can interrupt about 100 times more current than in air at given voltage

- The basic requirement in arc extinction is not primarily the dielectric strength, but high rate of recovery of dielectric strength. In SF6 gas, the electrons get attached with molecules to become ions. Thereby, the dielectric strength is quickly regained. Problems connected with current chopping are therefore minimized.
- In SF6 CB, The gas is made to flow from a high pressure zone to a low pressure zone through a convergent-divergent nozzle. The mass flow is a function of the nozzle-throat diameter, the pressure ratio, and the time of flow. the nozzle is located such that the flow of gas covers the arc . The gas

- The gas flow attains almost supersonic speed in the divergent portion of the nozzle., thereby the gas takes away the heat from the periphery of the arc, causing reduction in the diameter of the arc. Finally, the arc diameter becomes almost zero at current zero and the arc is extinguished. The arc space is filled with fresh SF6 gas and the dielectric strength of the contact space is rapidly recovered due to the electro-negativity of the gas. The single flow pattern (Fig. 23a) and double flow pattern (Fig. 23b) are used for arc extinguishing in single-pressure puffer type and double-pressure type SF6 circuit breakers.



(a) Single axial flow pattern



**Figure 23 Arc extinction in gas flow circuit breakers  
(Gas flows from high pressure to low pressure)**

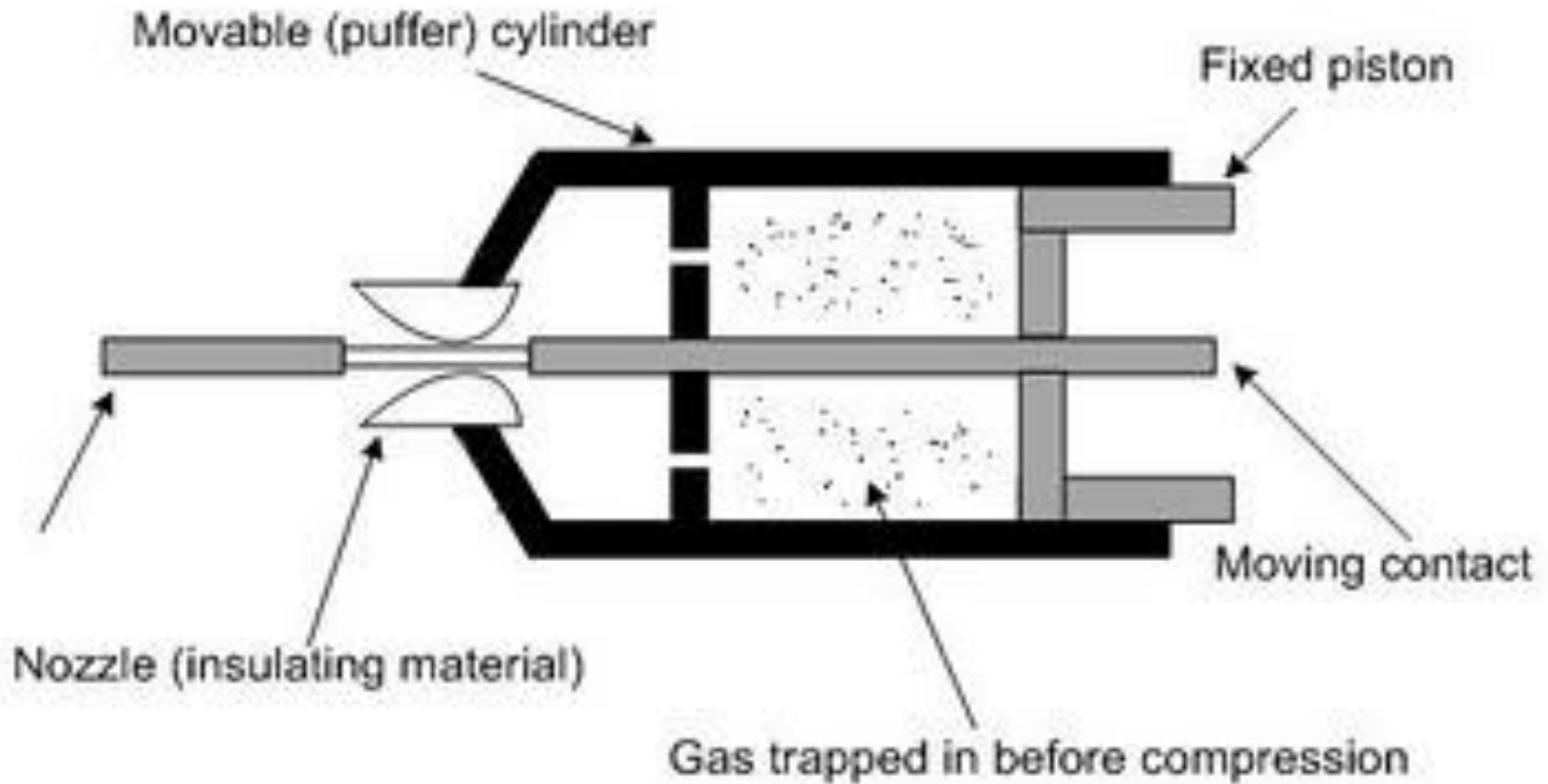
## single pressure puffer type circuit breaker, with single flow quenching medium

- When breaker is fully closed, the pressure in the puffer cylinder is equal to that outside the cylinder.
- During opening stroke, puffer cylinder and moving contact tube start moving.
- Gas gets compressed within puffer cylinder.
- After a certain travel, contact separates and arc is drawn.
- However, compressed gas flows from higher pressure to lower pressure through the nozzle.

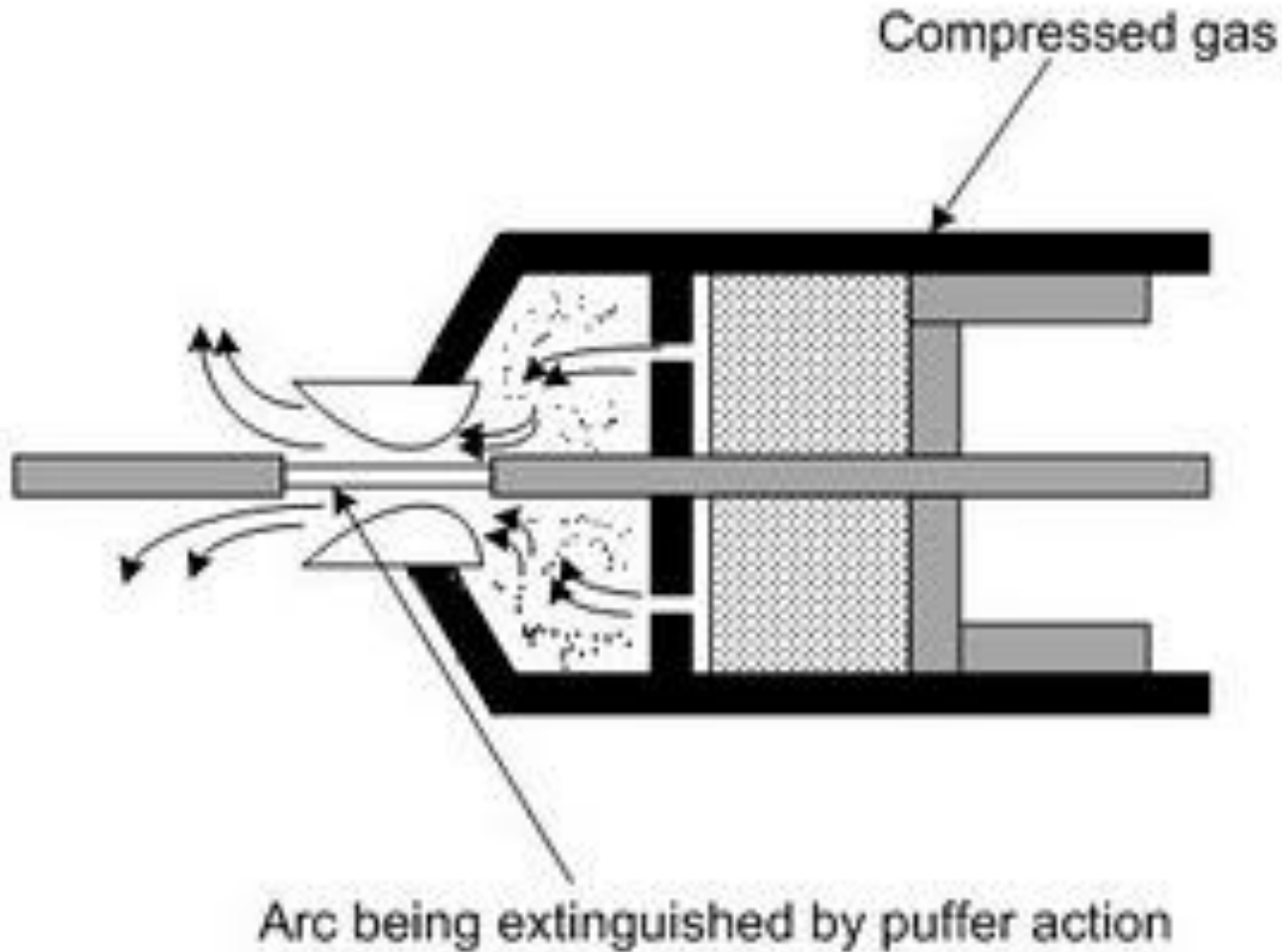
## 5.4.4 Single Pressure Puffer Type SF6 Circuit Breaker

- This type of circuit breakers employs the principle of puffer action, illustrated above. Figure 24(a) illustrates the fully closed position of the cylinder.





(a)

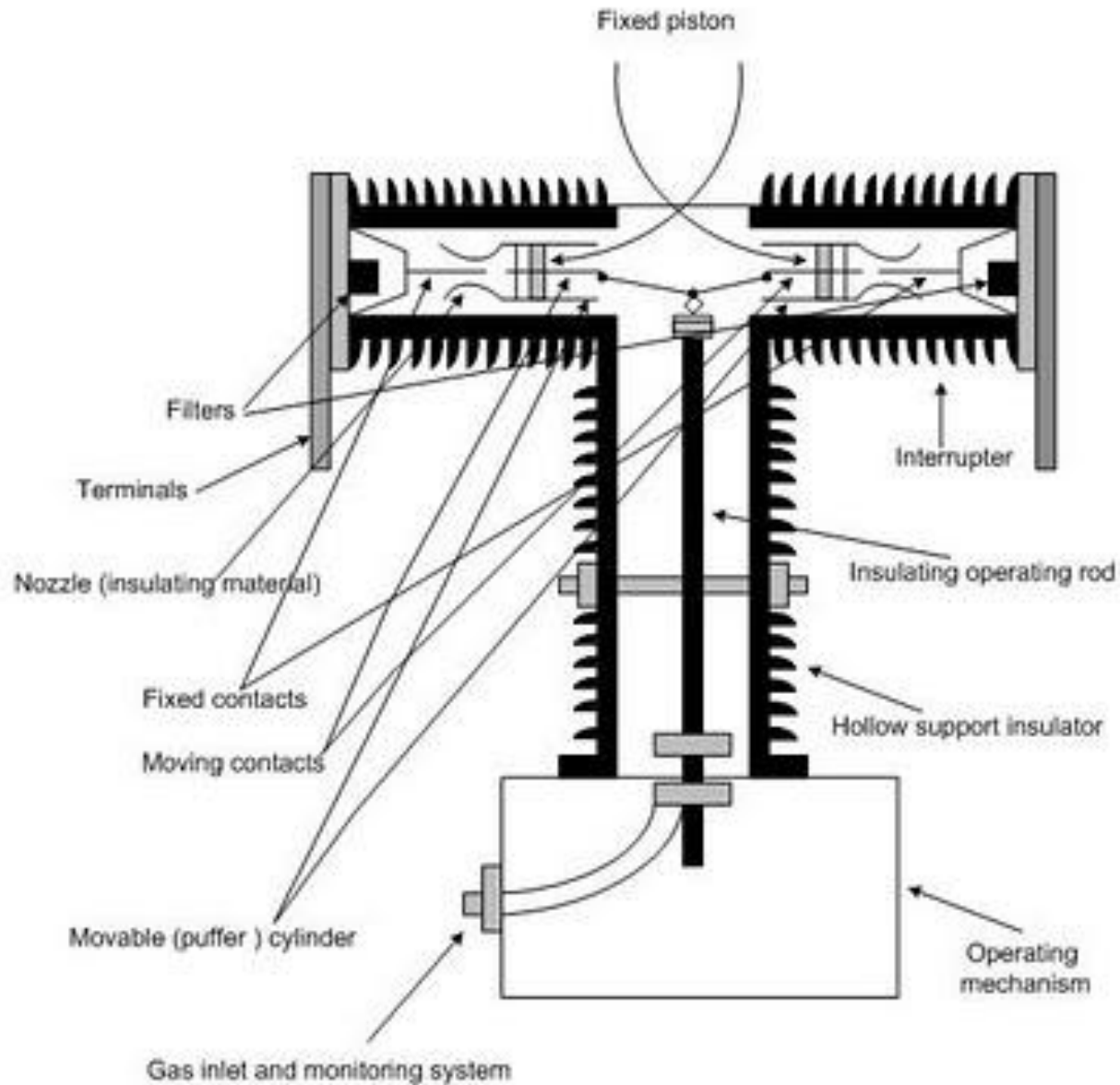


( b )

Figure 24 Puffer action principle

- The moving cylinder is coupled with the movable conductor against the fixed piston, and there is a relative movement between the moving cylinder and the fixed piston.
- The gas is compressed in the cavity.
- This trapped gas is released through the nozzle, during arc extinction process.
- During the travel, of the moving contact and the movable cylinder, the gas puffs over the arc and reduces the arc diameter by axial convection and radial dissipation.
- At current zero, the arc diameter becomes too small and the arc gets extinguished

- The puffing action continues for some time, even after the arc extinction, and the contact space is filled with cool, fresh gas.
- Figure 25 illustrates the configuration of a 245 KV/420 KV single-pressure SF6 circuit breaker. The two interrupters are mounted on the hollow support insulators. The operation mechanism, installed at the base of the insulators, is linked with the movable contact in the interrupter, by means of insulating operating rod and a link mechanism.



**Figure 25. One pole of 245 KV puffer type SF6 circuit breaker**

- The circuit breaker is filled with SF6 gas at a pressure of about 5 kgf/cm<sup>2</sup> . During the opening operation, the operating rod is pulled downwards by the operating mechanism. the link mechanism converts the vertical motion into horizontal motion. The contact and the movable cylinder, in the interrupter, are moved against the fixed position.
- Break-time up to 3 cycles can be achieved by puffer principle described above. For achieving 2 cycle break-time, differential position is used, in which the puffer cylinder and piston move in opposite directions, thus reducing total stroke and time of travel.

## 5.4.5 Merits and Demerits of SF6 Circuit Breaker

- Outdoor EHV SF6 CB has less number of interrupters per pole than ABCB and MOCB. It is simple, less costly, maintenance free compact.
- The gas is non-inflammable and chemically stable. The decomposition products are not explosive. Hence there is no danger of fire or explosions.
- Same gas is re-circulated in the circuit. Hence requirement of SF6 gas is small in the long run. No replacement is required for at least five years.
- Ample overload margin. For the same size of conductors, the current carrying ability of SF6 CB is about 1.5 times that of ABCB because of superior heat transferability of SF6 gas.

- The breaker is silent and does not sound, like ABCB, during operation.
- The sealed construction avoids the contamination by moisture, dust, sand, etc.
- No cost for compressed air system as in ABCB.
- Maintenance required is minimum. The breaker may need maintenance once in four to ten years.
- Ability to interrupt low and high fault currents, magnetizing currents, capacitive currents, without excessive over voltage. Sf6 gas CB can perform the various duties like clearing short line faults, opening unloaded transmission lines, capacitor switching, transformers, reactor switching. etc. much smoothly



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- Short break time of 2 to 2.5 cycles.
- High electrical endurance, allowing at least 25 years of operation without reconditioning
- Possible compact solutions when used for GIS or hybrid switchgear.
- Integrated closing resistors or synchronized operations to reduce switching over voltages.
- Reliability and availability.
- Low noise level.

## • 5.4.6 Some Demerits of SF6 Circuit Breaker

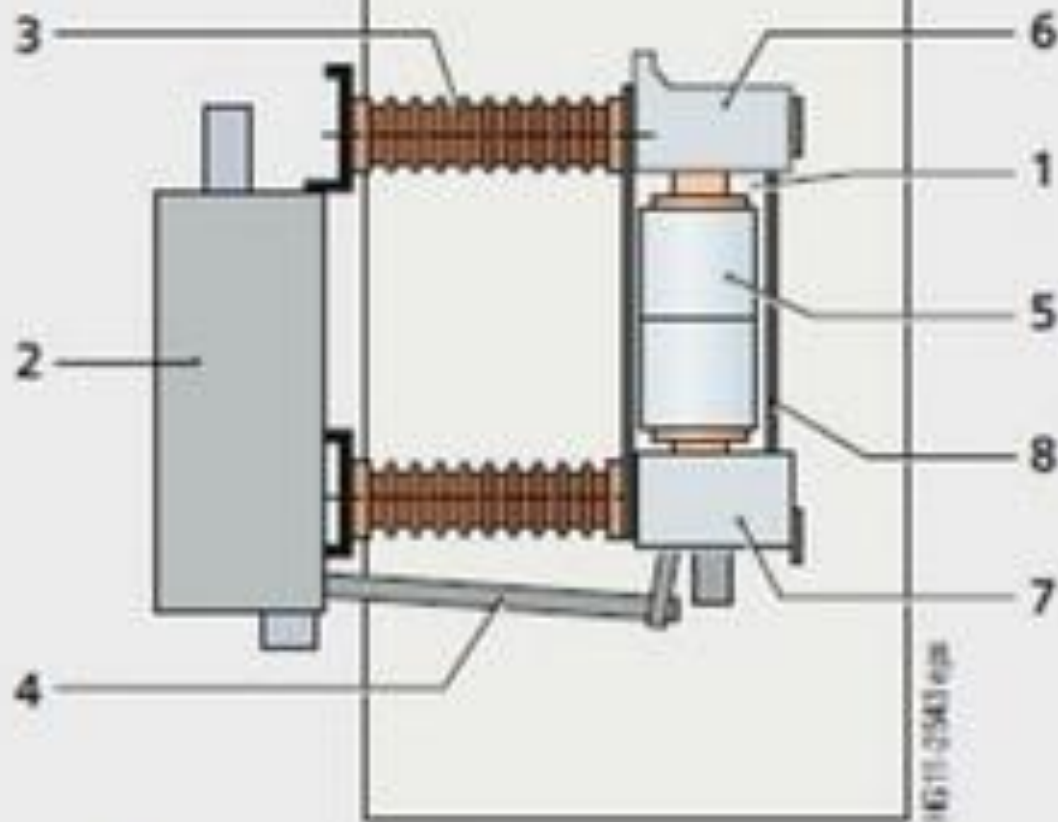
1. Sealing problems arise due to the type of construction used. Special materials are necessary in construction. Imperfect joints lead to leakage of gas.
2. Arced SF6 gas is poisonous and should not be inhaled or let-out.
3. Influx of moisture in the system is very dangerous to SF6 gas circuit breakers.
4. The double pressure SF6 CB is relatively costly.

5. The internal parts should be cleaned thoroughly during periodic maintenance, under clean, dry environment.
6. Special facilities are needed for transporting the gas, transferring the gas, and maintaining the quality of the gas. The deterioration of quality of the gas affects the reliability of the SF6 circuit breaker.

# 5.5 Vacuum circuit breaker

## 5.5.3 Construction of Vacuum Circuit Breaker

- The vacuum circuit breaker comprises one or more sealed vacuum interrupter units per pole (Fig. 30). The moving contact in the interrupter is connected to insulating operating rod linked with the opening mechanism. The contact travel is of the order of a few milli-meters only. The movement of the contacts within the sealed interrupter unit is permitted by metal-bellows.



**Circuit-breaker structure**

- |                           |                             |
|---------------------------|-----------------------------|
| 1 Pole assembly           | 5 Vacuum interrupter        |
| 2 Operating mechanism box | 6 Upper interrupter support |
| 3 Post insulator          | 7 Lower interrupter support |
| 4 Operating rod           | 8 Brace                     |

**Figure 30 Construction of vacuum circuit breaker**

# Vacuum circuit breakers can be classified in the following two categories:

- Vacuum interrupters installed in indoor switchgear and kiosks rated up to 36 KV (Fig. 31).
- Vacuum circuit breakers suitable for outdoor installation and having two or more interrupters in series per pole (Fig. 32).



**Figure 31** 12 kv indoor vacuum circuit breaker

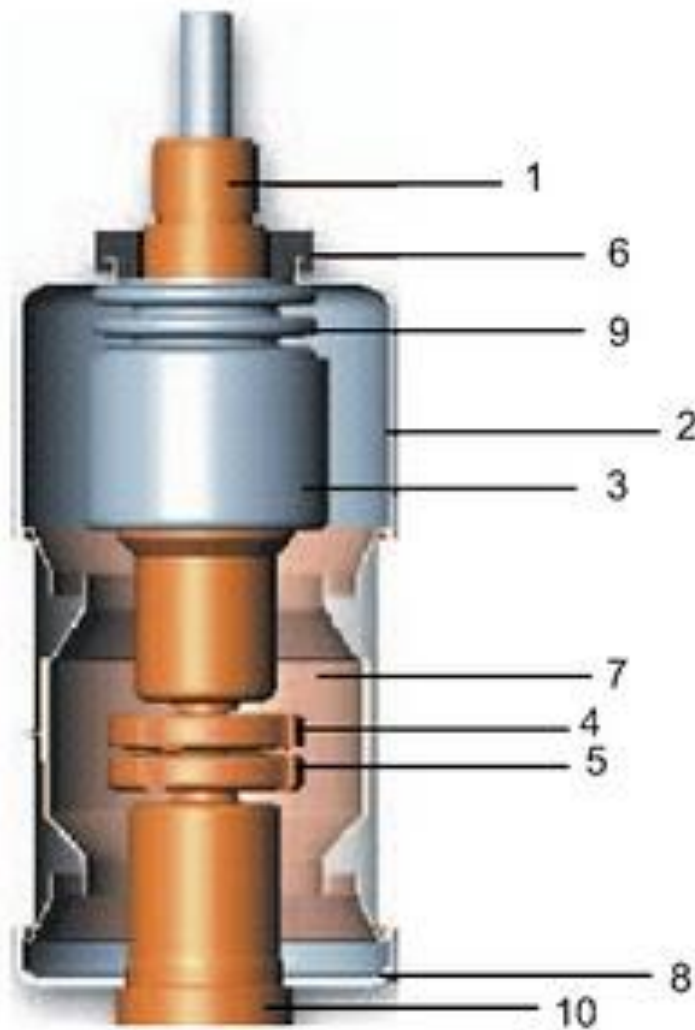




**Figure 32** 12 KV outdoor vacuum circuit breaker

- The structural configuration of the circuit breakers of two categories mentioned above is quite different as it can be seen, though the basic interrupter unit is based on same principle of operation.
- The multi-unit vacuum circuit breakers rated 72.5 KV and above have been developed and installed in England and U.A.S. However, they are not very popular and are not likely to be preferred to other types of circuit breakers.
- For voltage up to 36 KV, vacuum circuit breakers employing a single interrupter unit have become extremely popular for metal enclosed switchgear, arc furnace installation, switchgear in generating stations and industrial applications.

The construction of the vacuum chamber is relatively simple. As it can be seen in Fig. 33, it consists of a pair of contacts (4; 5), one of which is mobile (5), enclosed in a vacuum dense shield, soldered to ceramic or glass isolators (3; 7), upper and lower metal covers (2; 8) and a metal screen (6). The movement of the mobile contact in relation to the immobile one is provided by means of using a bellows element (9). Chamber outputs (1; 10) serve to connect it to the main current circuit of the breaker. It is necessary to state that only special metals that are vacuum dense and cleaned of dissolved gases are used in vacuum chamber shield manufacturing : copper and special alloys as well as special ceramic composition (usually it is 50%-50% copper-chrome) that provides high breaking capacity, low deterioration and resistance to the appearance of welding points on the surface of the contacts.



**Figure 33 Construction of vacuum interruption chamber**

Cylindrical ceramic insulators together with the vacuum space when the contacts are open provide insulation between the chamber outputs when the circuit breaker is in the opened position. To prevent metal steam condensation on the surface of the ceramic insulators, which causes damage to the electric strength of the insulators, a metal screen (Fig. 34) is used that "intercepts" and absorb metal steam formed during the switching. By doing this it prolongs the durability of the chamber (electrical endurance). The level of vacuum in the modern arc extinction chambers equals  $10^{-7}$  -  $10^{-6}$  Pa, which provides the durability resources for the chambers for their entire term of use because the necessary insulation parameters of the vacuum space are reached at  $10^{-3}$  Pa. Experience shows that during the process of switching, the level of vacuum slightly rises due to the condensed metal steam absorbing the residual



Figure 34 Model of contact system AEC

## 5.5.4 Merits of Vacuum Circuit Breakers

The vacuum switchgear has been successfully developed and is gaining rapid popularity. The vacuum switches are likely to be popular for wide range of applications. These switches devices have several merits such as :

1. VCB is self contained and does not need filling of gas or oil. They do not need auxiliary air system, oil handling system, etc. No need for periodic refilling.
2. No emission of gases, pollution free.
3. Modest maintenance of the breaker, no maintenance of interrupters. Hence economical over long period.

4. Breakers forms a unit which can be installed at any required orientation. Breaker unit is compact and self contained.
5. Non-explosive
6. Silent operation.
7. Large number of operation on load, or short circuit. Suitable for repeated duty.
8. Long life of the order of several hundred operations on rated normal current.
9. Constant dielectric. There are no gas decomposition products in vacuum and the hermetically sealed vacuum interrupter keeps out all environmental effect.



10. Constant contact resistance. In vacuum, the contacts cannot be oxidized, a fact which ensures that their very small resistance is maintained through their life.

11. High total current switched. Since contact piece erosion is small, rated normal interrupted current is up to 30.000 times; and rated short circuit breaking current is on the average of a hundred times.

The above reasons, together with the economic advantages offered, have boosted acceptance of the vacuum arc quenching principle.

## 5.5.5 Demerits of Vacuum Circuit Breakers

1. The vacuum interrupter is more expensive than the interrupter devices in other types of interrupters and its cost is affected by production volume. It is uneconomical to manufacturer vacuum interrupters in small quantities.
2. Rated voltage of single interrupter is limited until very recently to about  $36\sqrt{3} = 20 \text{ KV}$  above 36 KV, two interrupters are required to be connected in series. This makes the breaker uneconomical for voltage rated above 36 KV.
3. Vacuum interrupters required high technology for production.

5. In the event of loss of vacuum, due to transient damage or failure, the entire interrupter is rendered useless. It cannot be repaired at site.
  
6. For interrupter low magnetizing currents, in certain range, additional surge suppressors are required in parallel with phase of a VCB.