

the breaking process with a Fluarc SF6 puffer type circuit-breaker

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Summary

After a brief recall of the operation of an SF6 puffer type circuit-breaker, the author analyses the physical phenomena which develop, after the separation of contacts, during the period of "waiting" for the current to pass through zero and at the current zero point. The possibilities of simulated operation are then stated.

The purpose of circuit breakers is to interrupt all load currents or fault currents. They are equipments with contacts which separate, whatever breaking technique is used. It is thus inevitable that an electric arc arises from the instant when the contacts separate until the current reaches its natural zero, where it remains zero in spite of the restriking voltage if interruption is successful. This arc plays a fundamental role in current breaking. In the following pages, we shall examine the physical phenomena which appear in chronological order, that is:

- the period of "waiting" for the current to pass through zero, called the arcing period, during which the heat developed by the arc given up by the system must be quickly dissipated.
- the current zero point, after which the system voltage reappears between the contacts. This is defined by the circuit which basically comprises an electromotive force in series with a small reactance and a parallel RC circuit.

We shall leave aside the examination of

the restriking voltage form and concentrate on the performance of the circuit breaker in the presence of the stresses in the arcing period and at the current zero point.

Of the different breaking techniques available, we have chosen, to illustrate this study, the puffer technique in sulphur hexafluoride SF₆. There are other methods of interruption in SF₆, for example displacing the arc by the effect of a magnetic field created by the current. The two breaking processes are based on the simple principle of relative movement of the arc with reference to the SF₆ gas.

SF₆ has been chosen in preference to other gases since, of the various harmless and easily obtainable gases, it is an excellent arc quenching medium. It is well known as a high-performance dielectric permitting miniaturisation of high voltage switchgear. It is also:

- an effective thermal conducting agent during the arcing period,

■ a highly electronegative gas when it is decomposed by the arc, on account of its fluorine atoms, which play a vital role at the instant when the current passes through zero.

Before examining these different phenomena in more detail, it may be useful to give a brief description of the operation of puffer type switchgear.

The puffer process is simple: movement of the moving parts simultaneously causes compression of a small volume of gas behind the puffer piston. (On this example the main contacts are concentric with the arcing contacts).

The gas thus compressed remains captive during the first third of the travel and only begins to escape between the arcing contacts from the instant when they separate. This precompression time makes it possible to obtain a pressure difference without delay, that is, a flow of gas by forced convection.

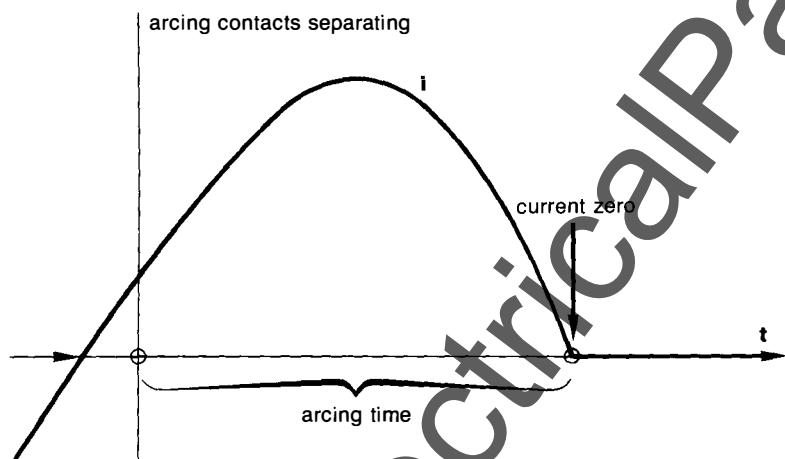


fig. 1
chronological diagram of the breaking process.

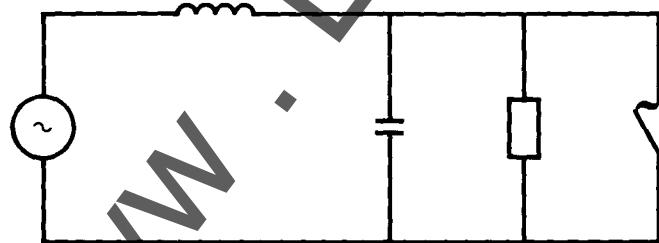


fig. 2
schematic diagram of short-circuit breaking.

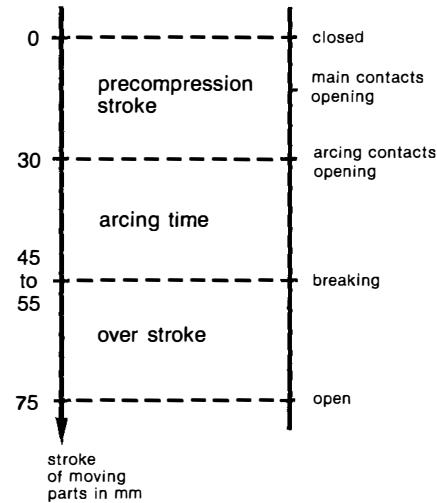
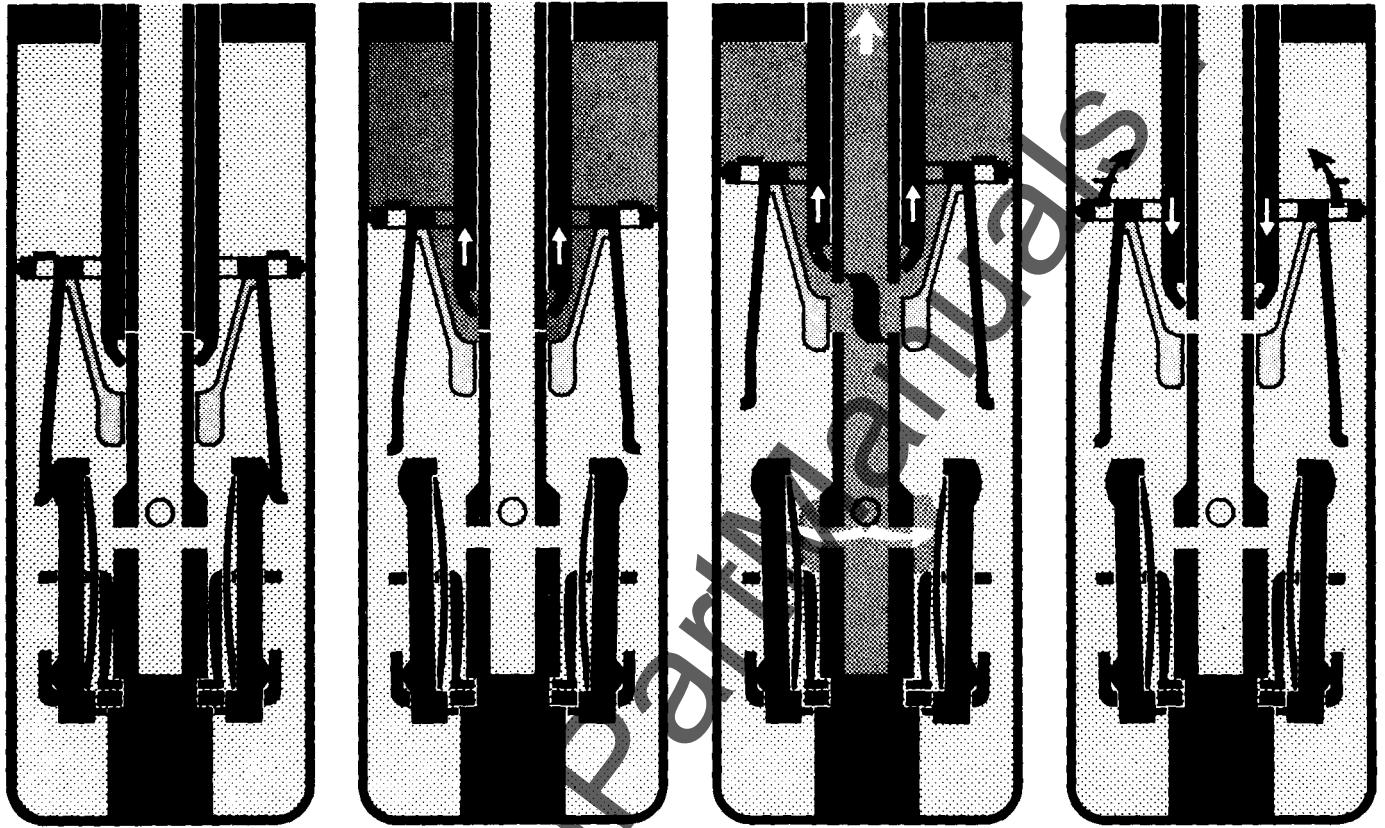


fig. 4.
operation of a puffer type SF₆ circuit breaker.



Closed position
The main contacts and the arcing contacts are closed.

Precompression
The SF₆ gas is compressed by the piston integral with the main moving contact. The main contacts separate.

Arcing period
The arcing contacts separate. The compressed gas thus released is directed by the nozzle and cools the arc by forced convection.

Closing operation
A valve opens on the piston to enable it to move rapidly during closing.

fig. 3
operating diagram of a puffer type circuit-breaker.
(On this example the main contacts are concentric with the arcing contacts.)

the arcing period

During the arcing period the arc is cooled by convection in that a certain quantity of hot gas is replaced by cold gas. This is not a surface phenomenon; the cold gas is brought in perpendicularly to the direction of flow to promote the mixing of hot gas and cold gas. Heat exchange by radial conduction is very low compared with this.

We could also expect heat exchange by radiation, on account of the high temperature of the arc. In fact, the exchanges are small because radiation is from the peripheral layers only.

Finally the heat exchanges during arcing take place chiefly by convection. The energy supplied by the system in time dt to a mass dm of gas is:

$dw = VI dt = h dm$, V being the arcing voltage and h the enthalpy per unit of

mass. We again have $VI dt = h \rho s dx$, ρ being the density, s the cross section of the arc and dx the path taken by the mass dm in the time dt .

Hence $VI = h \rho su$, u being the velocity of the gases.

The power transmitted is directly dependent on this velocity. The laws of gas flow teach us that this velocity cannot be indefinitely increased to increase the mass flow of the hot gas. It is advantageous to stay in the vicinity of the speed of sound in the gas. This speed can only be obtained by suitable structural arrangements and sufficient switching energy. The hollow tubular contacts facilitate the rapid flow of hot gases and causes instability of the arc root, preventing wear on the arcing contacts.

The puffer technique is remarkably effec-

tive, as it is sufficient to inject only a small quantity of gas between the contacts. With the Fluarcs FB and FG, the quantity of compressed gas injected at the throat of the nozzle is 5 grammes during breaking; to limit the temperature of the arc to 10 to 15 000 °K, it must be possible to evacuate the heat produced by the arc which is approximately 30 000 joules when interrupting a current of 25 kA. The gas enthalpy curve shows that one gramme of gas is sufficient to carry this energy.

During arcing, the space occupied by the arc at the throat of the nozzle depends on the instantaneous current value. The cross section of the arc is proportional to this and consequently is subject to the same sinusoidal variation. At high current values, the arc may occupy the whole of the available space, blocking the flow of gas.

Indeed, the mass flow in the arc is very low compared with the flow of cold gas around the arc, as the gas density is low at the temperature of the arc. This is what is known as the "clogging" effect.

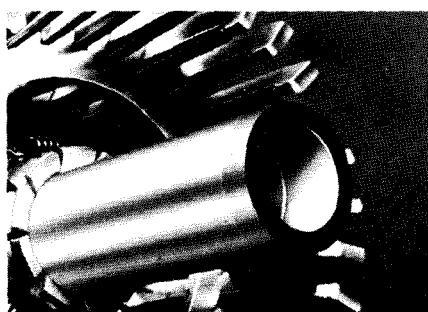


fig. 5
contacts of the Fluarc FC 2500 A
breaking capacity 40 kA at 24 kV.

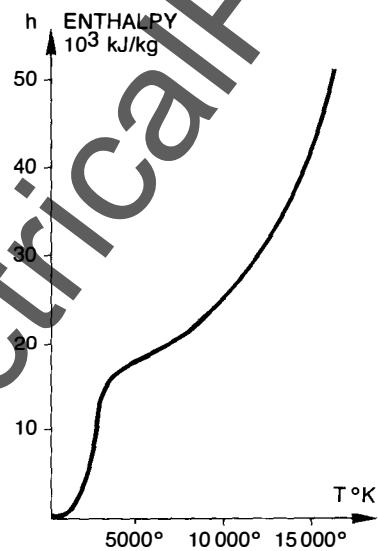


fig. 6
enthalpy of SF₆ as a function of temperature.

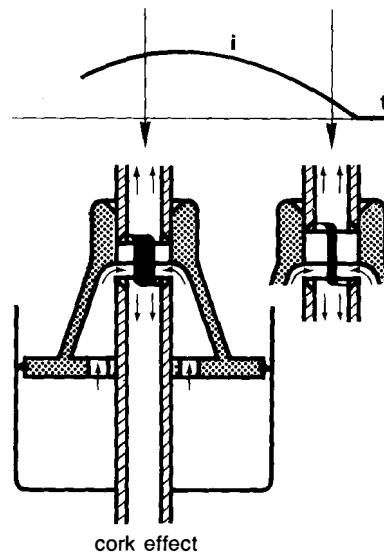


fig. 7
clogging effect.

The total mass flow at the nozzle throat is thus low when instantaneous current values are high, but it rises very quickly as soon as the current falls, and shortly before current zero it is greater than that which would occur on opening without current.

The clogging effect is beneficial for two reasons:

- when the circuit breaker opens on a high current it keeps a larger amount of gas in reserve than when it interrupts lower currents. It does not act "blindly" whatever the current; it is better prepared for the passage through current zero in heavy currents, and it avoids briefly interrupting low currents, as the mass flow on non-load is modest.
- interruption of a heavy current causes braking in the opening movement. This braking limits the distance between contacts, that is, the length of the arc and thus the energy dissipated in the arc. It is therefore important to stress that the arc is relatively short, in the order of 15 mm for a 12 kV, 24 kV, or 36 kV equipment, that is, smaller than the contact diameter.

The clogging effect is optimally adjusted on the Fluarc FG2. If it is not very great, the advantages mentioned above are reduced. If it is too marked, braking is excessive, the distance between the contacts at current zero is too small and the dielectric strength is insufficient. By adding a weight to the moving piston, that is, at precisely the point in the kinematic chain which is subject to the braking, the braking effect can be limited; at the highest current values, optimum braking is obtained at a reasonable level of control energy. Only 250 joules are required for an opening operation. This is in fact the same energy as that required to open circuit breakers of different breaking principle.

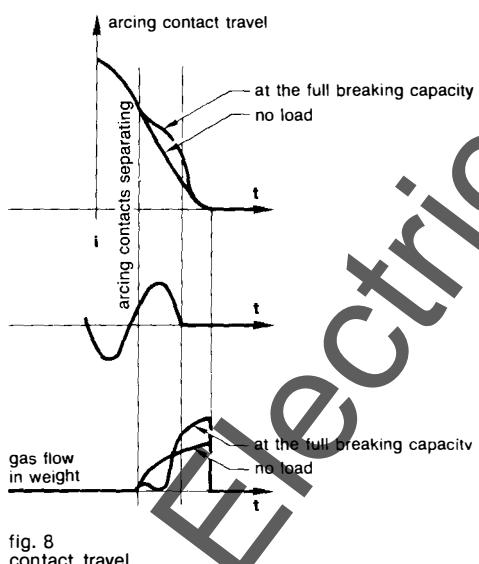


fig. 8
contact travel.

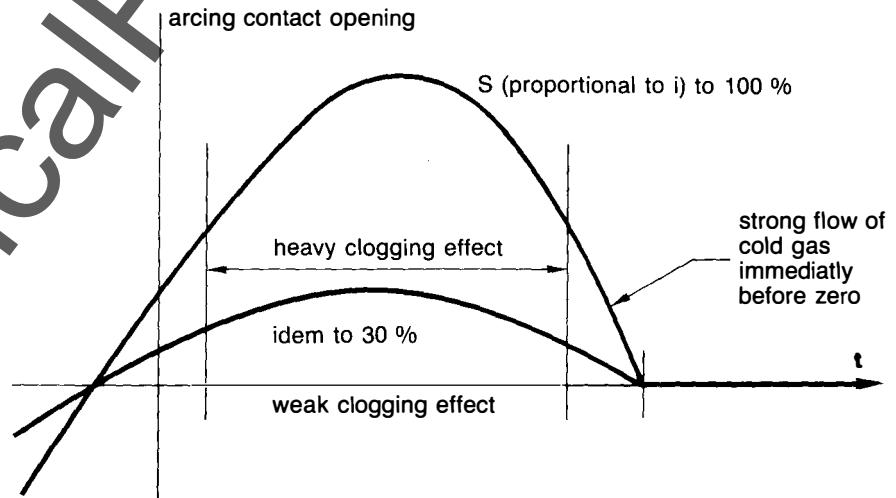


fig. 9
variation of the arc cross sections at 30 % and 100 % of the breaking capacity.

current zero

In the vicinity of the current zero point, the arc is cooled chiefly by **radial conduction**. This good conduction from the centre of the arc towards the exterior is explained in the curve of fig. 10. On this curve a very pronounced thermal conductivity peak around 2100°K may be observed.

The arc is confined to a small diameter where it is still conductive and it is surrounded by a sheath of cooler gas which does not conduct the electric current but does conduct heat very well.

This heat exchange with cold gas takes place rapidly. Another very interesting property is the low time constant of electrical conductivity. Calculations confirmed by experiment have shown that this time constant was in the order of one microsecond, that is, one hundred times smaller than that of most other gases, air in particular.

The good performance of SF₆ at the moment of breaking can be explained by examining what happens at the atomic level. SF₆ starts to dissociate at around 2000°K . At 2400°K it is half dissociated, whereas for nitrogen this temperature is 7000°K . At the temperatures at which SF₆ is conductive, dissociation is complete.

The arc consists of a number of molecules and neutral or ionised atoms and some free electrons. Among these particles, fluorine plays a vital rôle on account of its great affinity for electrons. When the arc is extinguished, there is a sudden large reduction in the number of free electrons.

To confirm this hypothesis, the concentration of negative ions caused by this capture was measured. Everything else being equal, it is 100 times greater than in air.

Shortly before the current passes through zero, the whole volume of gas between the contacts, falling in temperature, passes 2000°K . This is the point at which almost all the particles recombine into molecules of SF₆.

After successful breaking at current zero, the moving parts continue their travel to give sufficient opening compatible with the insulation level of the equipment. This further travel, prolonging the puffer effect, sweeps the space between the contacts, and prevents any late restriking. The dielectric providing insulation between the contacts is thus SF₆ gas which retains its initial dielectric properties. Deterioration of the gas is extremely slight, as the decomposition of SF₆ at high temperature is reversible. Only wear on the arcing contacts needs to be considered. This is very satisfactory for the user, who does not need to worry about the state of the gas, and who can, if he so wishes, check the degree of wear on the circuit breaker contacts without having to open the poles, nor make any other inspections. The marks provided on the linkage mechanically connected to the contacts correspond to the butting of new or worn contacts.

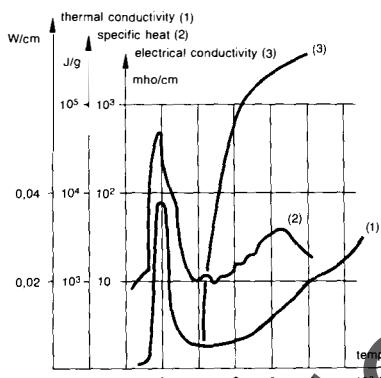


fig. 10
thermal and electrical conductivity of SF₆
as a function of temperature

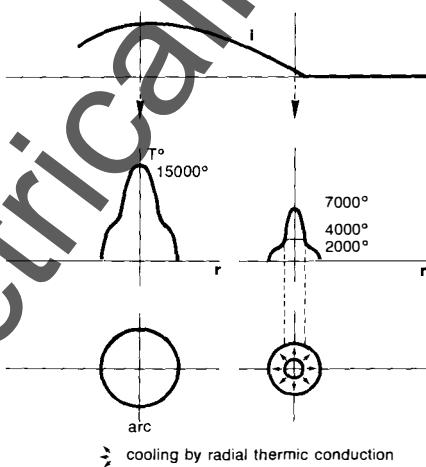


fig. 11
cooling by radial
thermal conductivity.

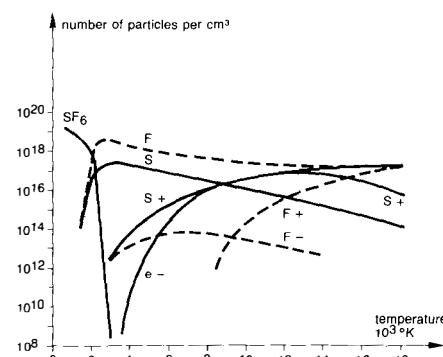


fig. 12
number of particles per cm^3
as a function of temperature.

To summarise, the different modes of heat exchange in the SF6 puffer type circuit breaker are as follows:

	radial conduction	convection	radiation
arcing period	slight exchange	major exchange	slight exchange
current zero point	major exchange	slight exchange	slight exchange
after breaking	slight exchange	major exchange	no exchange

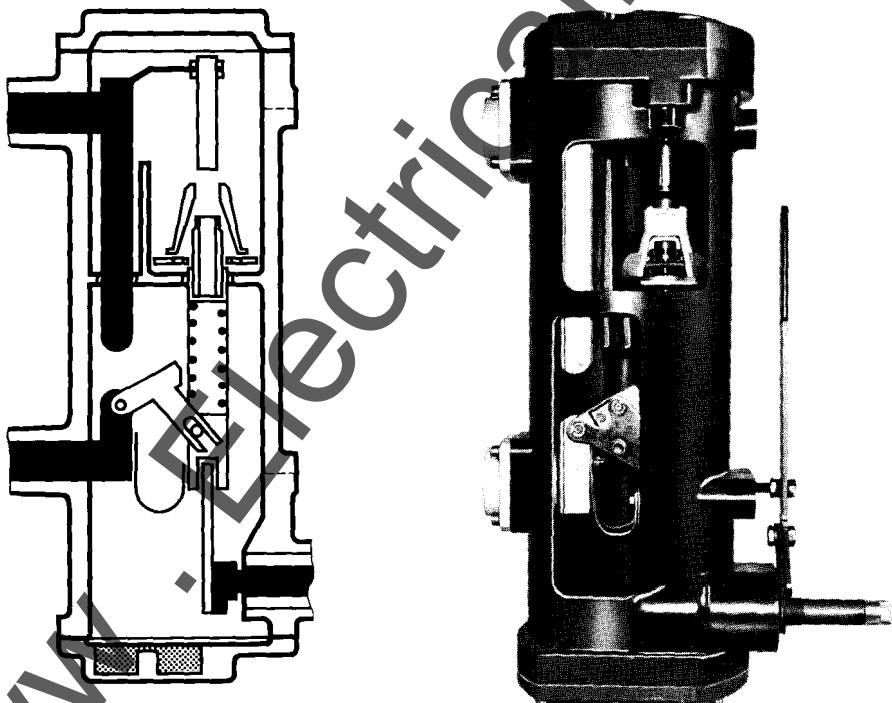


fig. 13 and 14
the live parts of Fluarc FG2.

simulated operation

Major progress has been made in forecasting and perfecting the operation of puffer technique circuit breakers, on account of the simplicity of the phenomena involved, compared to those in other types of circuit breaker, and on account of the scientific advances in knowledge of physical constants and data processing.

Calculation does not give a formal indication of whether the switchgear can interrupt a given current at a given voltage, but it serves to determine most of the mechanical and thermodynamic parameters during opening of the switchgear.

We know how to determine the movement of the circuit breaker contacts on no-load using classic rules starting from

the motive forces given by the springs and the resistive forces due to the increasing pressure behind the piston; the masses are all brought to a suitable point for the requirements of the calculation. Then the equation force = mass \times acceleration is written and integrated to obtain the space/time function.

All this stage it is possible to select different geometrical parameters.

Experience has confirmed the values obtained to within a few percent. Onload operation can be obtained by applying the gas clogging theory, reducing the nozzle throat cross section by an amount equal to the cross section of the arc, which itself is a function of time.

The results of the calculation were compared with those obtained experimentally

to adjust certain coefficients and after a little trial and error, the accuracy of the calculation was improved very satisfactorily.

To summarise, at present we have a means which can be used either to design the equipment to achieve optimum operating conditions rapidly (predetermining the geometry, motive forces, pressures), or during tests to interpret the performance of the equipment under different circumstances (asymmetrical operation, finding the limits of the equipment, etc...)

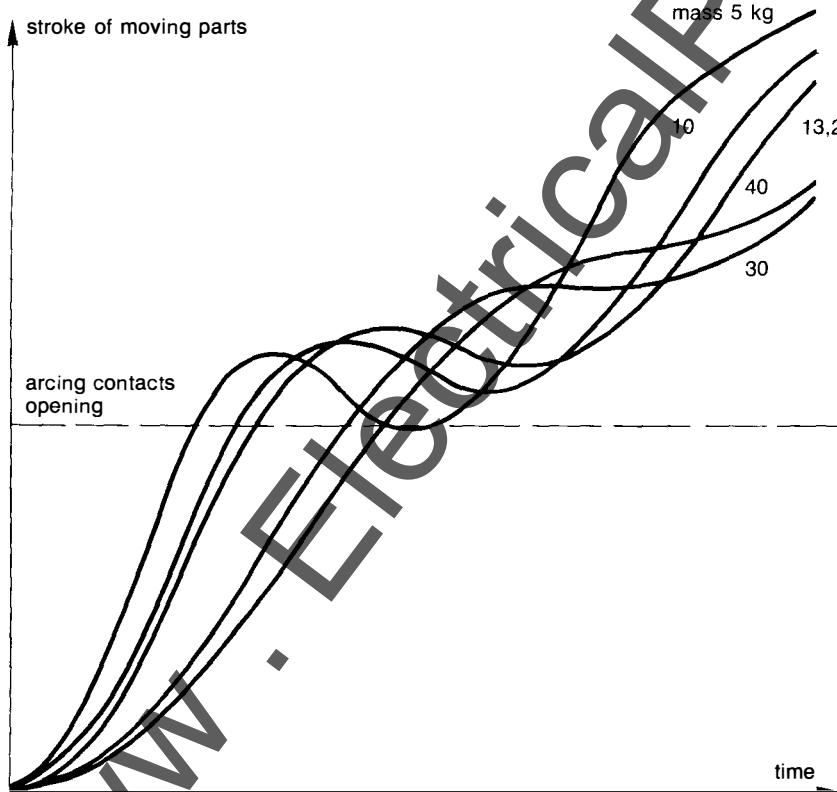


fig. 15
travel of the arcing contacts as a function of time.



fig. 16
the movement is made to rotate by a shaft round which there is a sealing bush with flanged gaskets: one or 30.000 switching cycles in 20 years without maintenance.

conclusions

Puffer SF6 circuit breakers of the Fluarc type have low switching energy requirements. They are equipped with a standardised drive mechanism that can be used in conjunction with several breaking techniques.

The concept of a long-life, sealed, maintenance-free unit marks a major advance over traditional breaking techniques, and this is complemented by the use of classic technology and components available on the world market. The forecasting and control of physical phenomena which occur during breaking are considerably improved compared with those in other breaking techniques. These phenomena are exactly repeated with no scatter from one unit to another. Such advantages permit more rapid developments in these circuit breakers than in others which are more closely tied to experimentation.

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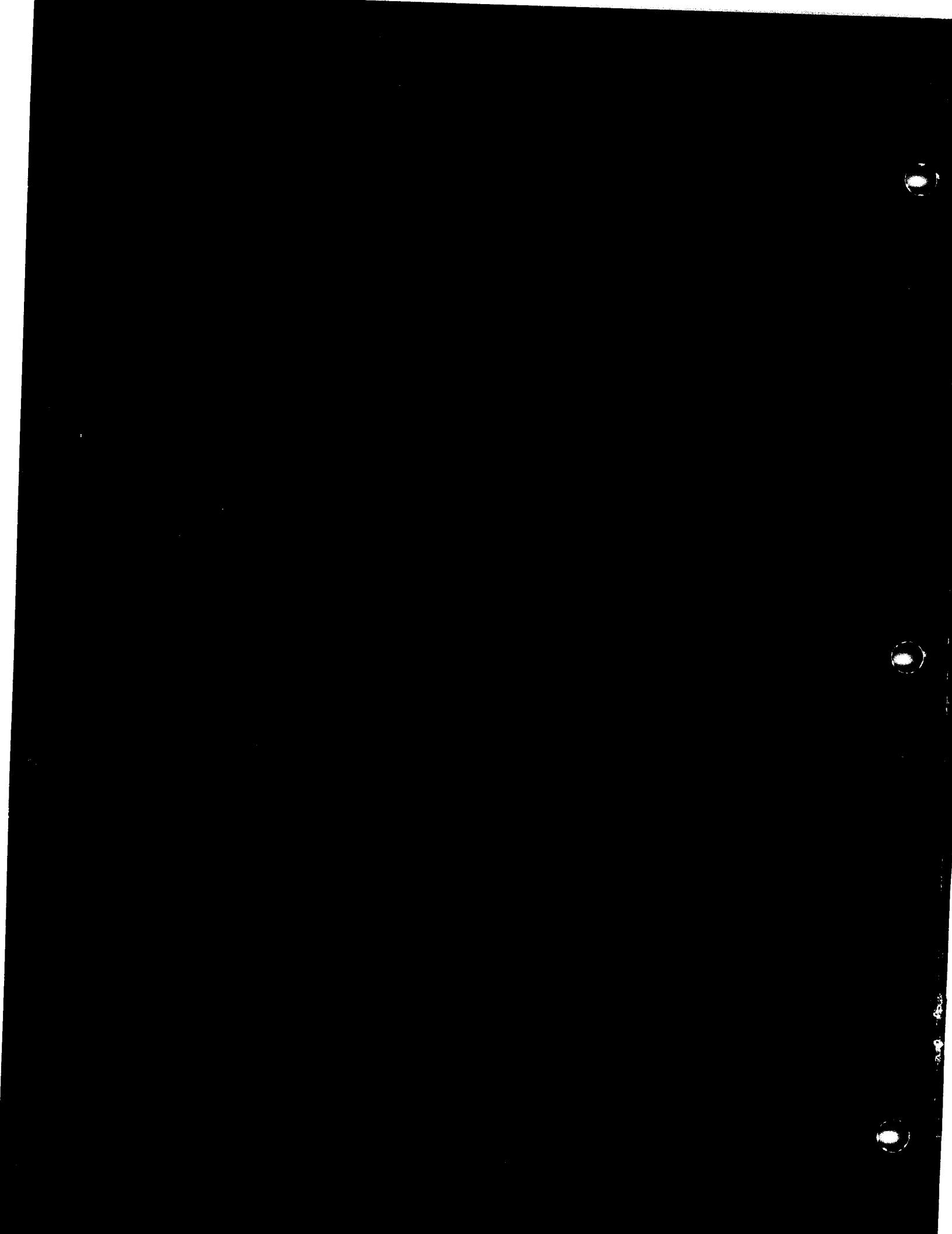
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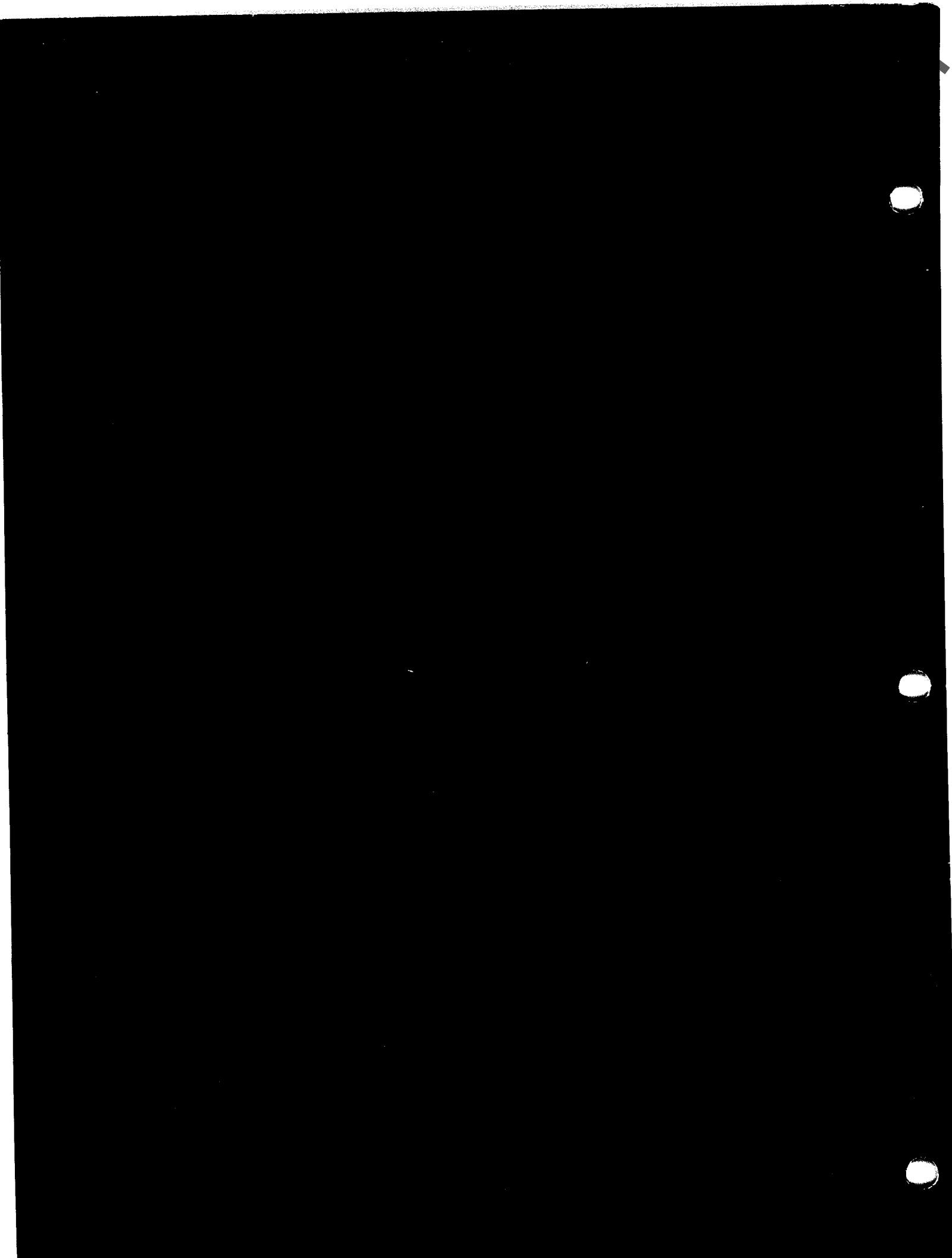
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