very useful exp'l data
SF_6 and Air
nat. conv.

FUSE-ELEMENT IN SF_6 ATMOSPHERE

A. Wolny
Technical University of Gdańsk
Gdańsk, Poland.

1. Abstract.

Behavior of fuse-elements made of copper, silver or aluminum heated up to the melting point in SF_6 atmosphere has been described. Heat transfer from fuse-element was investigated as well as corrosive influence of SF_6 on the metals. For comparison the tests were repeated for air and argon. At the temperature of several hundreds degrees of Celsius was observed less difference between heat transfer in SF_6 and air. Pressure had little influence in these conditions.

It was proved that aluminum is resistant at high temperature in contrast to copper and silver which corroded rapidly over 300°C.

2. Introduction.

Application of SF_6 to circuit-breakers, load-switches and encapsulated switch-gear does not involve higher temperature than 200°C, if very short arcing times are not taken into account. So, the all experience on SF_6 low chemical activity towards most metals and insulating materials, as well as on its thermal properties concerns rather the moderate temperature.

Recently more and more interest in SF_6 fuses has been observed, both as independent devices [1,2] and as parts of hybrid ones [3]. Investigation of the behavior of fuse-elements in SF_6 atmosphere up to melting point became imperative.

To provide good extinguishing conditions the amount of metal vapour in quenching chamber should be limited, therefore good conductors only, such as silver, copper and aluminum can be considered for fuse-elements. Melting temperatures of the two first metals approach 1000°C. Therefore one can expect certain grade of dissociation of SF_6 particles, which may change heat transfer conditions and provoke corrosion [4].

Aluminum melts easier, but its melting point at 659°C seems still to be high enough to expect any changes of SF_6.

3. Experimental.

Test chamber was made of quartz glass cylinder 40 mm in diameter, 132 mm long. Its walls were 4 mm thick. Electrodes cross-section of 50 mm^2 permitted application of currents up to 50 A without excessive heating.

Tested fuse-elements were made of copper, silver or aluminum wires, 0.8, 0.85, and 1.6 mm in diameter correspondingly . Their total length was 70 mm, but only a straight segment about 35 mm long was investigated. To diminish axial flow of heat the both ends of fuse-element were curled. Two turns 4 mm in diameter, separated 2.5 mm were applied. Each sample was equipped with two welded probes 0.3 mm in diameter, 32 mm apart for voltage drop measuring and on this way determination of temperature.

The fuse-elements surface was degreased before their installation.

The test chamber was positioned horizontally. After having hermetised it air was evacuated and argon let in. Tested fuse-element was heated up to the red glow to uniform its structure and stabilize resistivity. After such conditioning over several minutes the gas was pumped out and then the chamber was filled up with SF_6 under desired pressure. The sample was fed with stabilized current not exceeding 50 A DC, until the voltage drop got stable magnitude. This took several minutes. The last (stable) reading was used for calculation of temperature. First three terms of series representing the resistivity-temperature function were applied The temperature was calculated from the formulae:

$$\Delta T=K_1\cdot[(K_2\cdot R/R_o-1)+\sqrt{(K_2\cdot R/R_o-1)^2+(R/R_o-1)\cdot K_3}$$

where: $K_1=A_1/2A_2$, $K_2=A_7/A_1$, $K_3=4A_2/A_1^2$ (1)

A_1, A_2, A_7 are material constants taken from [5]. They denote: A_1, A_2 are the first and second thermal resistivity constants and A_7 is the delatation constant. If any changes of the sample surface were not observed a different current or pressure was established and the test was repeated.

Results of the experiment were extrapolated to examine their convergence to independently measured FMC. The deviation of temperature was less than 5 percent.

SF_6 heat transfer investigations were carried out at pressures 50, 100, 180, 260, 340 and 420 kPa and temperature up to approximately 800 ^oC. Bulk of results was obtained for the copper wire.

Applying the same test method comparison was made with air and argon.

After having built approximated i-T profiles serving for determination of the temperature due to the set current the corrosive activity of SF_6 was investigated under the pressure of 100 kPa. The test current was maintained over 3 hours. Next the sample was thoroughly examined. Tenfold optical magnification was applied.

4. Results.

4.1. Heat transfer.

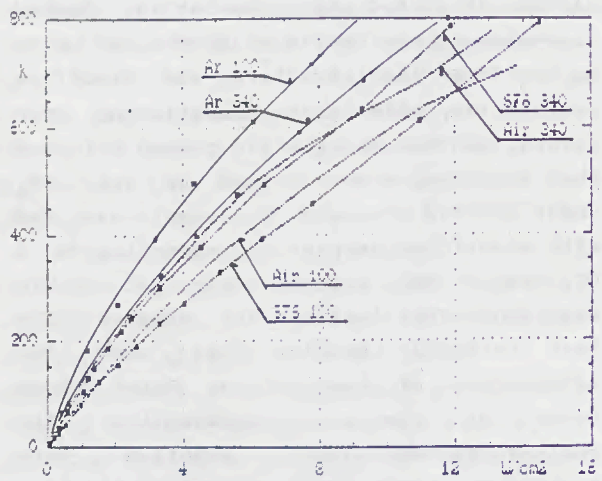

Fig. 1. Temperature rise of cooper fuse-element in SF_6, air and argon (100, 340 kPa)

The temperature rise versus heat power flux profiles for SF_6, air and argon under the pressure of 100 kPa and 340 kPa are given in Fig.J One can see that the advantageous cooling features of SF_6 known for moderate temperature are not true over 600^oC for copper wire, although pressure has still propitious influence. Up to this temperature under any pressure the difference between SF_6 and air is never greater then several percent only and seems to be slightly less than that measured for larger objects [6].

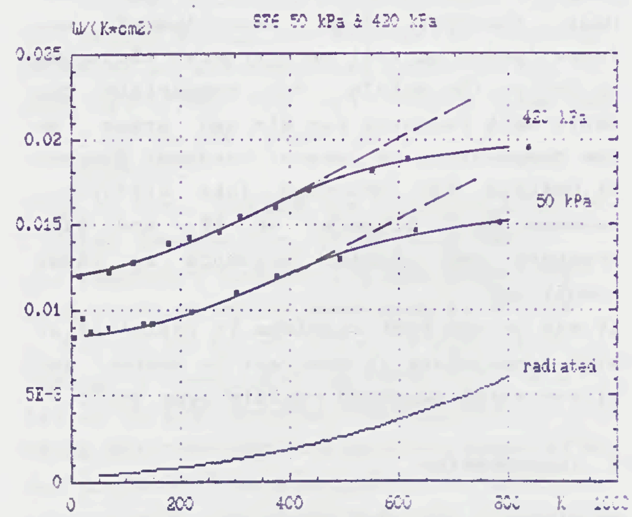

Fig. 2. Heat transfer coefficient K_{ht} for SF_6 (50 kPa and 420 kPa).

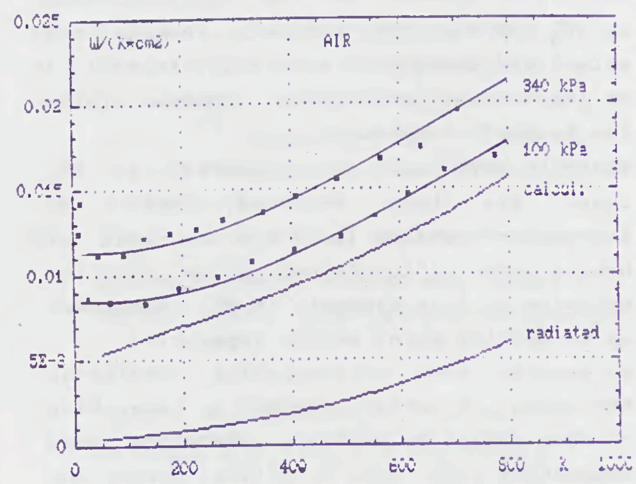

Fig. 3. Heat transfer coefficient K_{ht} for air, measured and calculated (100 kPa).

Pressure rise enhances heat transfer but in a very moderate way. The increase from 50 kPa to 420 kPa at 200^oC gives 42% in profit only. At higher temperature it is even less, due to influence of radiation, which is independent from gas pressure.

The SF_6 generalized heat transfer coefficient K_{ht} in function of temperature rise for full range of tested pressures is presented in Fig.2.

$$K_{ht} = P \,/\, [\, S \cdot (T - T_o)] \qquad (2)$$

$P = \Delta U \cdot I$ - dissipated heat power,
S - sample surface,
T, T_o - sample and ambient temperature.

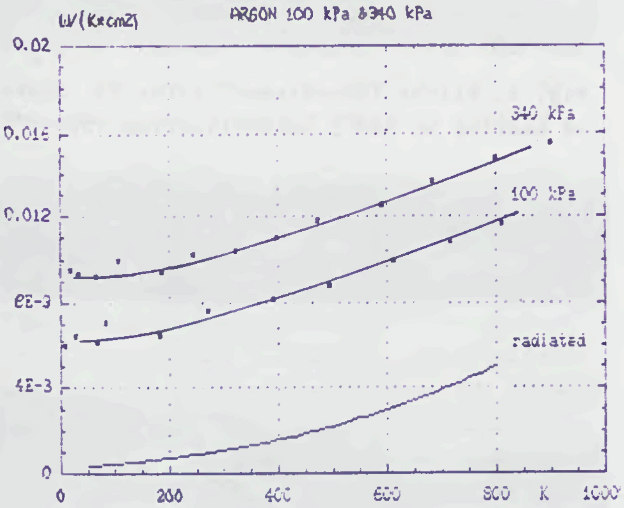

Fig. 4. Heat transfer coefficient for argon (100 kPa and 340 kPa).

Data for the lowest (50 kPa) and the highest (420 kPa) pressures, determining the belt filled with intermediate values for other conditions are given only. Similar results for air and argon, but for more narrow range (100-340 kPa) are shown in Fig. 3 and Fig. 4. On both of them radiation heat transfer coefficient K_r is also plotted providing emissivity ε=0.6 for SF_6 and air or ε=0.5 for argon. It is supposed that copper oxides layer enhancing emissivity is more transparent in argon.

$$K_r = \varepsilon \cdot \sigma \cdot (T^4 - T_o^4)/(T - T_o) \qquad (3)$$

At higher temperature close to 600°C the K_{ht} coefficient in SF_6 begins to rise slower and slower, differently than in other gases. The trend similar to argon or air should follow the dashed line charted in the Fig. 2.
The K_{ht} coefficient calculated for free convection in air in natural conditions based on the data given by Szargut [7] is also shown in Fig. 3. The table data were approximated. The results of measurements indicate that the cooling conditions in the experiment were better than those supposed in calculation, maybe partly because of not fully compensated axial heat flow.
Comparison of K_{ht} coefficients for SF_6 and air at 100 kPa and 340 kPa is presented in the Fig. 5. The difference is several percent. The curves are very similar up to about 500°C. Above this threshold the cooling properties of SF_6 decline in tests with copper fuse-element

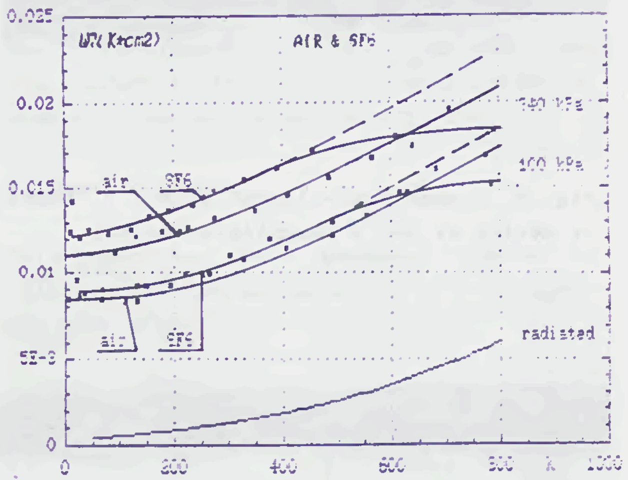

Fig. 5. Heat transfer coefficient K_{ht} for SF_6 and air (100 kPa and 340 kPa).

Used method of measurement is less accurate for very low (small voltage drop and possible inhomogeneity) and very high temperature rises (possible oxidation). Therefore larger deviation of results has been observed in these conditions.

4.2. Corrosive properties of SF_6.

Up to about 250 - 300°C nothing special was observed, but over 300°C, gas initially colorless turned very slightly yellowish. Glass walls lost their transparency and became a little milky. After having opened the test chamber the sharp, irritating smell was felt. No chemical analysis was done because of the small volume of the chamber.
The first alterations of copper fuse-element were observed at 300°C. Over 400°C it got dark patches, and next a dark brown surface layer built of tiny

bubble-like formations (Fig. 6). The diameter of wire increased in 50%. Further temperature rise consolidated that layer. It was fragile and split easily while bending the wire (Fig. 7).

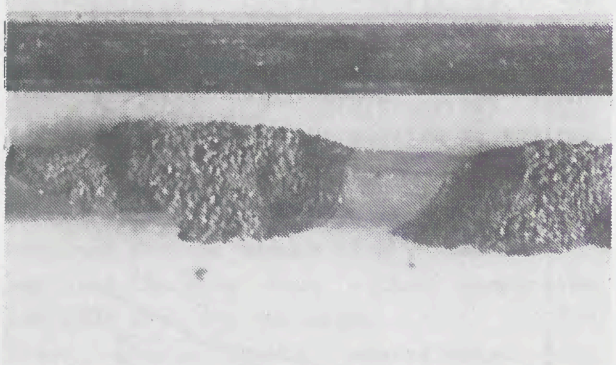

Fig. 6. Copper fuse-element after 3 hours of heting at 660°C (magnification 15).

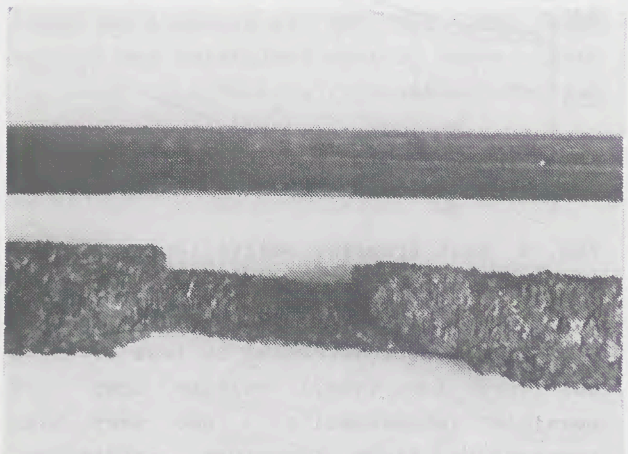

Fig. 7. Copper fuse-element after 3 hours of heating at 830°C (magnification 15).

The silver fuse-element began changing at a little higher temperature. At about 400°C white powder was observed on the surface, that became more cohesive during the heating. The corrosion product layer was thinner than that on the copper wire, but still the diameter increased in 35%. It split also facile (Fig. 8).
The aluminum wire did not change at all even close to melting point (Fig. 9).
Any inhomogeneity of surface could produce differences of features of created corrosion product layers (Fig. 5).

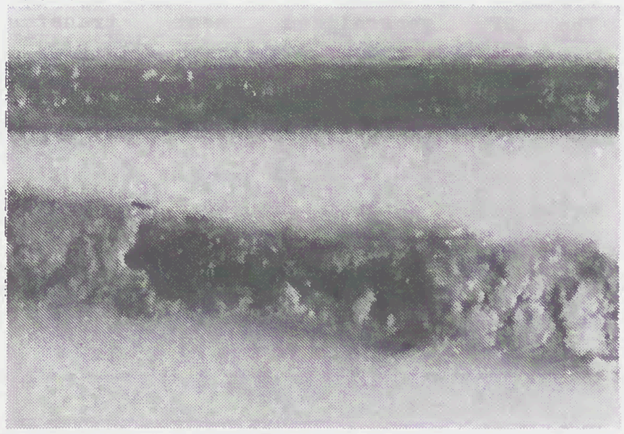

Fig. 8. Silver fuse-element after 3 hours of heating at 780°C (magnification 15).

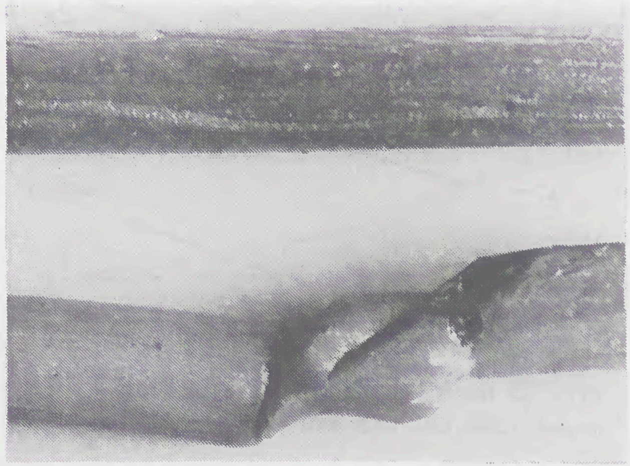

Fig. 9. Aluminum fuse-element after 3 hours of heating at 625°C (magnification 15).

5. Discussion.

5.1. Heat transfer.

The chamber and fuse-element diameters ratio is so big that the heat conduction can be fully omitted.
At low temperature radiation may be also neglected but over 300-400°C this is not the case. At 600°C it can constitute almost 30% of the heat flux (Figs. 2-5). Luckily it is easy to calculate if emissivity of fuse-element is known.
The real problem creates convection. Its heat transfer coefficient K_k is defined by Nusselt number correlation

$$Nu = K_k \cdot d / \lambda = C \cdot (Gr \cdot Pr)^m \qquad (4)$$

where the Grashof number Gr is defined as the Prandtl number $Pr = c_p \cdot \rho \cdot \nu / \lambda$. (6)

The thermal capacity c_p, thermal conductivity λ, kinematic viscosity ν, and the gas density ρ are functions of temperature and pressure. The constants C, and m depend upon the value of Gr Pr product and should be determined experimentally. For SF_6 it lacks such data for the fuse operation conditions. Therefore it seems convenient to compare SF_6 fuse thermal features with the air ones. Up to 600^{o}C a coefficient (K_p) dependent upon pressure could be applied

$$K_{ht(SF)} = K_{ht(air)} \cdot K_p \qquad (6)$$

Its value may be constant for a given pressure and the pressure influence can be linearised as show results. Errors should not exceed few percent. Investigations carried out at lower temperature by Majzel [6] indicated also that pressure rise caused almost linear increase of the heat transfer coefficient.

Over 600^{o}C the sharp drop of rate of rise of the K_{ht} coefficient value may be probably provoked by coating of the sample with corrosion product layer. Therefore no interpretation of this feature and methods of evaluation can be given until additional experiments with materials chemically more resistant are completed.

Rate of rise of K_{ht} value slightly increases with the temperature rise for argon and air in the full range of tested temperatures. So, the oxidation of copper wire in air would have less influence than the corrosive activity of SF_6.

5.2. Chemical activity.

In accordance to the observations made, there is no doubt that the dissociation of SF_6 particles occurs over 300^{o}C, what can provoke corrosion. It was stated that the most endangered is copper and the most resistant is aluminum, unlikely to Howard's report [8] concerning lower temperature. Silver can be positioned in between.

In practice it could be said that exclusively aluminum is suitable for fuse-elements. Copper and silver could be used for short-circuit or time-lag with low melting point M-effect protection only.

6. Conclusions.

In large range of temperature the SF_6 thermal features are very similar to those of air, although SF_6 is several percent better one.

Therefore, the heating calculations could be performed in the same way as for air, using the same parameters but applying additionally a correction factor greater than 1.

The fuse-element in SF_6 applied for overcurrent protection preferably should be made of aluminum or coated with it.

7. Aknowledgement

This paper has been prepared thanks to valuable help in measurements of Mr Targonski M.Sc.E.E.

8. References.

[1] Akers D.J., SF_6 designs improve distribution switching and fusing, 1989 Power Technol. Intern., 267-268.

[2] Reason J., Revolution in switchgear, 1989, Electr. World (USA), 203, 57-62.

[3] Kacprzak B, Lipski T, Wolny A., Dwuczeciowy, piaskowo-prozniowy bezpiecznik wielkiej mocy o nieograniczonej zdolnosci wylaczania malych pradow, 1987, Zeszyty Naukowe Politechniki Poznanskiej,Elektryka, 34,51-58.

[4] Artur A., Preparation proprietes physiques, chimiques et applications generales de l'hexafluorure de soufre, Bull. SFE, 34, 514-523.

[5] Rex H.G., Calculation of models for adiabatic processes, 1984, Int. Conf. on Electrical Fuses and Their Appl., 35-51.

[6] Majzel E.S., Issledovanie teplovych svoistv gazovoj izolacji primieniajemoj v elektrotechniczeskich ustrojstwach, 1962, Elektriczestwo, 4, 54-57.

[7] Szorgut J., Termodynamika, 1976, PWN, Warszawa, Poland.

[8] Howard P.R., Insulating properties of compressed electronegative gases, 1957, Proc. IEE, 104, 123-137.

Session 3

FUSE DESIGN III