# Post – arc behavior in HV outdoor expulsion fuses


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### Abstract

HV outdoor expulsive fuses are popular and competitive switches for a protection against short-circuit in HV networks. Post-arc behavior is very important for breaking limits and the effects of turbulence plays one of the most important roles in the resistance restore. It is known that the turbulence plays the most important role in the arc decaying thanks to a high growth of the turbulent energy in the arc. We use the algebraic model of turbulent viscosity which is conceded this growth. In this paper results of the calculations, based on our theory, and comparison between theory and experimental data are presented.


Keywords: HV outdoor fuses, decaying arc, turbulence, turbulent viscosity.

## 1. Introduction

The high-voltage fuses are used for protection of power transformers, overhead and cable lines, and capacitors. For designing these fuses, it is necessary to solve a number of the interconnected tasks to support their reliable operation in various modes. One of these tasks is the optimization stream parameters extinguishing the arc. In the present paper, two aspects of the given tasks, namely, influence of the geometry of the channel and the turbulence of a flow for post-arc phenomena are considered.

Usually, on actuating the fuse, at burn-off of an insertion by fusion, the contact blade is released and, being thrown off under the influence of a spring, draws out behind itself a flexible tail. The arc elongates by the tail moves away and is extinguishing by the gas flow from the tube opening. The arc forming is axially blown by the quenching gas, which is forms during the burning-off of the burn-off element, and quenched. After the arc quenching the interval of gas providing the necessary isolation level formed.

As it has been told earlier, for designing the fuses, it is necessary to solve a number of the interconnected tasks. Experiments are very expensive, so we think that it would be good to have a model for calculating arc- and post-arc phenomenon, for predict breaking limit parameters in the new fuses design. In this paper we present such semi-empirical theoretical model that can be used for the task of optimization of the stream parameters extinguishing the arc is considered. One of the main parts of our model is the turbulence describing. As known, the interaction between the decaying arc and gas flow in the fuses plays the important role in increasing the arc resistance due to the axial convection and radial turbulent heat conduction. In addition, the turbulence in the post-arc mode intensifies heat transfer between the arc and the gas flow that accelerates temperature decrease and the resistance is quickly growing up. Experiments show that the turbulent energy in a volume unit of gas of the arc essentially increases in the vicinity of the current zero, and, hence, also the coefficient of the turbulent viscosity increases. Thus it is possible to show [1] that the latter increases to proportionally to the square root of the density growth in the arc, changing by tens times during the current decrease. In the present paper, the algebraic model of turbulence describing the process in the post-arc mode extinction taking into account this effect is offered. The model offered shows the good agreement between the calculated curves and experimental data, and can be applied in a wide range of initial and boundary conditions.

## 2. Model equations and boundary conditions

Calculations are based on the experimental data [2]. The turbulent arc in the stream formed by an axisymmetric supersonic nozzle is considered, thus the current in the arc changes in time under synthetic test. Interaction between the flow and the arc is described by the equations of Navie-Stokes added by continuity equation and balance of energy equation [1]. The Ohm’s law and models for the turbulent viscosity and for the radiation [1] add the system.

**Model of the turbulent viscosity.** The model of the turbulent viscosity describes two mechanisms of generation of turbulence in the flow: at the expense of shift stress and at the expense of the Rayleigh-Taylor instability. The coefficient of turbulent viscosity is given by:

$$\mu_t = (\rho\rho_e)^{0.5}\nu_t$$
$$\nu_t = \delta f_1 f \sqrt{\left[\left(C\delta\frac{\bar{\mathrm{v}}_\Delta}{\Delta}\right)^2 + \left(C_1(u_\mathrm{m} - \bar{u}_\Delta)\right)^2\right]} \quad (1),$$

where $\rho_e$ – density of the gas; ρ- density of the gas in point; δ - middle by the coordinate x arc radius; Δ - value of *r* where $r=1.5\cdot r_{0.15}$; $\bar{u}_\Delta$, $\bar{v}_\Delta$ - value of velocity u and v in the point $r=\Delta$, $u_m$ – axis value of velocity. Turbulent parameters using in model are $C=10^{-1}$; $C_1=4{,}9\cdot10^{-3}$; *f*, $f_1$ – empirical functions providing reduction of turbulent viscosity in the stream near the nozzle wall.

For stationary process we used model Eq.(1). Unsteady processed we calculated based on Weil test. Therefore, we used theory of “freezing” $\nu_t$. It mean that in all moment of time $\nu_t$ is defined as constant and it is number value is equal to it stationary value, during current decreasing.

The radiation model is described in paper [4] explicitly.

At carrying out of calculations it is considered that the channel is axisymmetric; its walls are impenetrable and adiabatic. The left electrode is in the input section of the channel. The right electrode is carried out for the channel limits.

**Breaking limit.** It is known from experiments [2, 5] that after current zero appearance the part of post-arc where the temperature is falling down more quickly than in another it. Therefore, it was considered that breakdown ability of gas would start to recover if the temperature on the arc axis reaches values of 3000К in one point at least. This length was chosen because it defines main part of the resistance in the post-arc phase. It was assumed that electrical breakdown (U) is being proportional to a section length on the post-arc axis (L - breaking length) on which temperature is equal or less than 3000К because this part of gas is non-conductivity. In the first assumption for the analysis of the breaking limit can be used a simple expression:

$$U(t) = C \cdot L(t) \cdot \left(\frac{p}{p_0}\right)^n \cdot \frac{t}{t_0} \qquad (2)$$

Where C is empirical factor; *L* - breaking length; *p* is the gas pressure on the length *L*; $p_0$=0,1MPa; *t* is the time last after the breaking length appearing; $t_0$ is equal $I_{max}/(dI/dt)$ to for the Wail test, $I_{max}$ – maximum current value. We define numerical values of experimental constants as: $C = 3; \quad n = 0.5$.

## 4. Results and discussion

Note, that we are interesting in breaking limits parameters of fuses. Therefore, we design semi-empirical model and we have to determine the empirical coefficients of the model from the experiment and calculation data comparing. Unfortunately, there are not enough detail experimental data for fuses parameters in the arc- and post-arc period. We tested our model based on the experimental data [2]. The paper [2] is devoted to arc- and post-arc phenomena in the supersonic nozzle. We assumed that data [2] can be used for testing fuse describe model based on two moments. First, the experiments [6] show that in the limit regime the pressure in the arc chamber can be very high. Secondly, research [7] shows that fuse with nozzle chamber is very effectively and arc quenched rapidly in it. Authors in [7] used fuse with nozzle in high-voltage installations at nominal current of over 2 kA. In view of told all above we choose experimental data [2] for testing our model.

The geometry of the nozzle for analyzing the post-arc phenomenon in the nitrogen [2] is presented in the Fig. 1. The inlet pressure is equal to 23atm, the outlet one is equal to 1atm. The current is changing with time according to the Wail's test. We have stationary value $I_{max}$=2кA, dI/dt = -23,5A/μs [2]. The current reaches zero and stops.

Three possible various types of the flow were considered:

A. The turbulent arc in the stream formed by the supersonic nozzle.

B. The laminar arc in the stream formed by the supersonic nozzle.

C. The turbulent arc in the stream formed by the nozzle with a pipe as a diffusor.

The results of these calculations are presented in Fig. 2-4.

Fig.2 shows the calculated curve averaged by the length axial temperature of the arc depending on time in comparison with the experimental data [2]. Also, figure plots the current as the function of time. Obviously, the calculated curve is in a good agreement with the experimental data in a steady state and at low values of temperature. At median values of temperature ($15000 \div 10000^0$К), the calculations give the results underestimated in comparison with the experiments. We relate this result to the fact that the model of radiation gives the integral losses of heat on radiation, disregarding an additional thermal emission at a recombination in the specified range of temperatures. However, at values of the temperature of interest in the present work, (low values temperatures) the agreement between the calculated curve and experimental data is satisfactory.

Fig. 3 shows the curves of the increasing breaking length *L* for three variants of the flow conditions. Obviously, that under flow 'C' condition delay period (time lasts from the current zero to breaking length occurrence) (24μs) is more, than in case of 'A'. For the laminar post-arc mode (flow 'B' condition) delay period is almost by 7 times more than that for the turbulent one (58 and 8.2μs after current zero, respectively).

In Fig. 4, curves of the average pressure along the breaking length, *p*, related to the input pressure, $p_{in}$, as the function of time after current zero for all variants of the flow conditions are presented. As seen in the figure in cases 'A' and 'C', when the flow is turbulent, the average pressure slowly changes with time, and are not much dependent on the diffusor part of the channel geometry. Computing under flow 'B' condition, the pressure in the channel is noticeably higher, than in two other case and falls with time from 0.7 at the moment of the beginning of current drop to 0.6 in 40 µs after current zero. Therefore, in this case the pressure reduction amounts approximately 15 %.

Thus, it is possible to state that in case of a laminar arc the delay period is unacceptably great. In case of a turbulent arc, the delay period is minimum in case of the presence of the diffusor parts extending (8.2 µs), and for 3 times greater in case of a cylindrical diffusor parts (24 µs). Thus, it is necessary to recognize as the best result the calculation for flow 'A' condition.

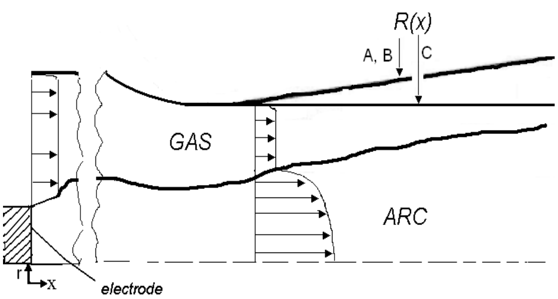


**Fig. 1:** Channel geometry.

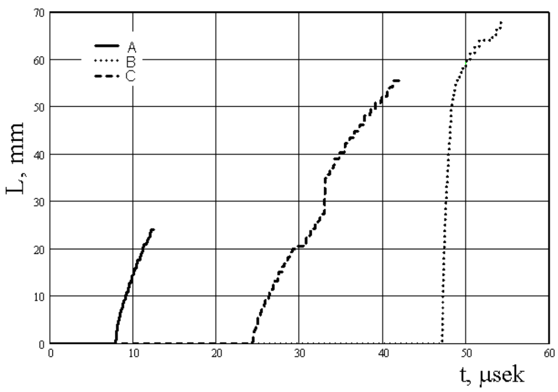


**Fig. 2:** Axial temperature as the function of the post-arc time.

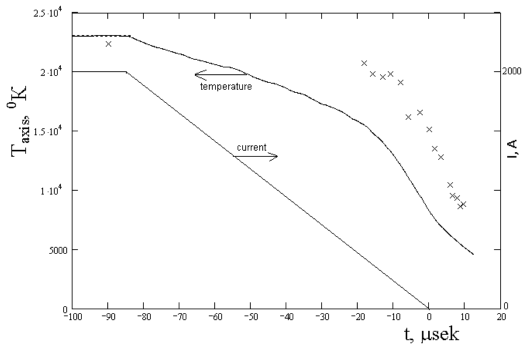


**Fig.3:** Break length $L$ as the function of the post-arc time.

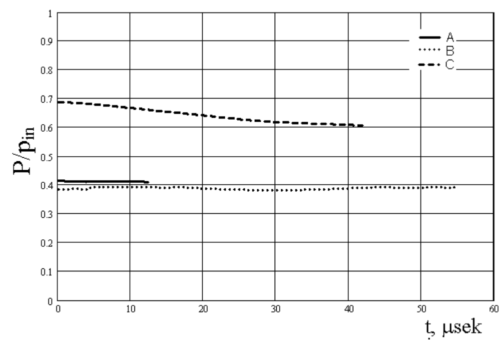


**Fig.4:** Relation $p/p_{in}$ as the function of the post-arc time.

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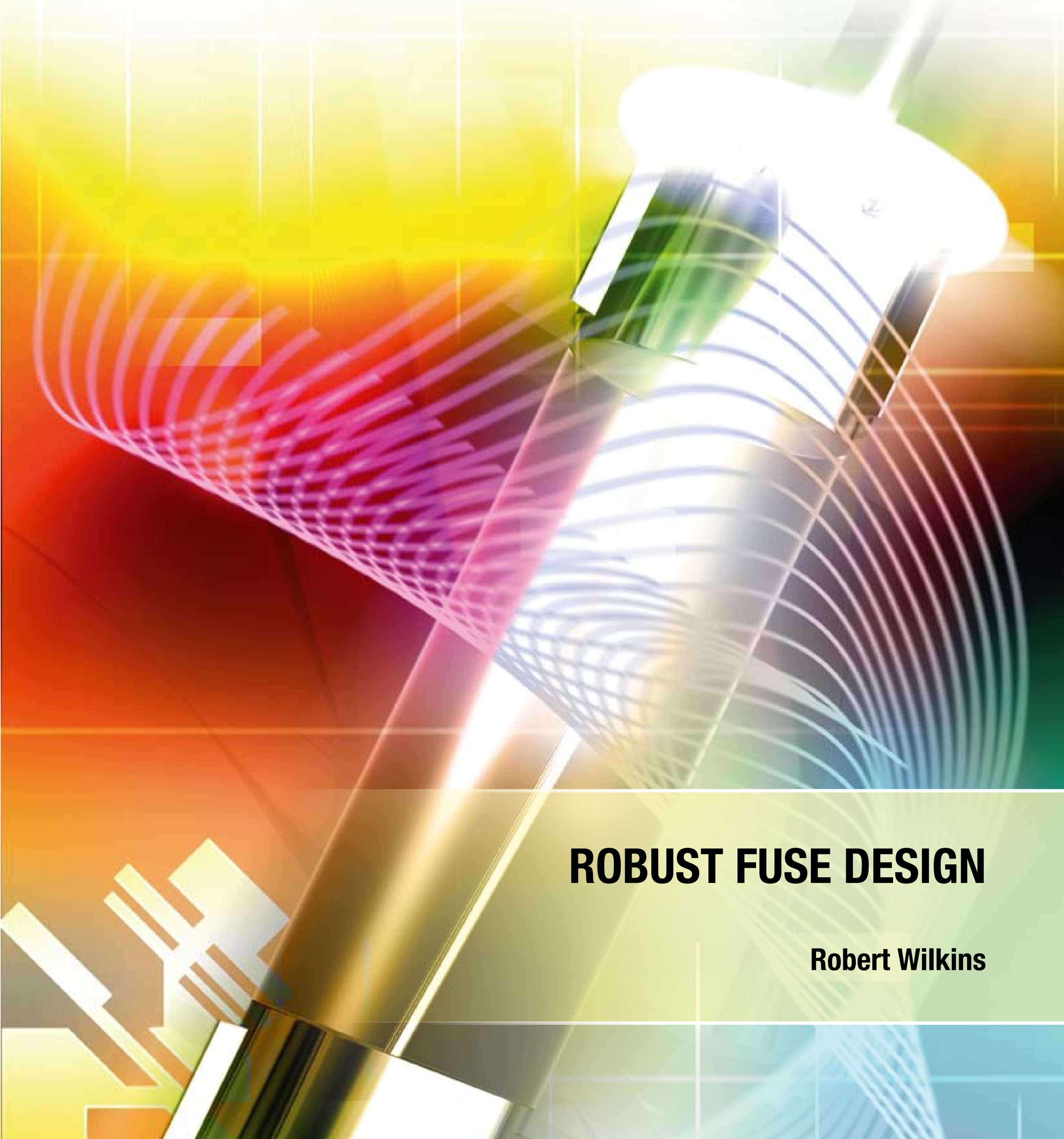

# ROBUST FUSE DESIGN

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