

# Analysis and Study on the Interrupting Characteristic of XRNT High-Voltage Current-Limiting Fuse

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**Abstract.** The idea of our project is derived from Hangzhou Boda Electrical Corporation Limited. The research is based on the pre-arcing time and Current Characteristic of High-voltage fuse, whose short circuit fault current can reach 9-35 times of current rating. The method adopts finite element numerical calculations for modeling and simulating fuse protector making rated current of 200 amperes. Besides, in order to provide a more correct result, we analyze and compare the simulation results with manufacturer's experimental Results, and propose the pre-arcing time of short circuit fault current by correcting vaporization point.

## Introduction

The subject originates from the Hangzhou Boda Electric Appliance Co., Ltd. It is a study and analysis on before arc time-current characteristic of high-voltage current-limiting fuse which is used for transformer protection. Based on 200A rated current fuse, we compute the characteristics of pre-arcing time-current through finite element numerical simulation. This work can provide reference for the future development and design of full range fuse.

## High Voltage Current Limiting Fuse Breaking Process

The breaking process can be generally divided into three stages: 1) When it arrives at a, the melt begin to melt; 2) The electric arc will be generated at the point of b; 3) After b, because of the cooling and extension effects of silica sand, the arc voltage will increase. When the arc voltage goes over the instantaneous value of the line voltage, it will stop going up and begin to drop along the bc line. Then it drops to zero at the point of c, which creates the best opportunity to extinguish arc.

As shown in Fig. 1. Where,  $t_1+t_2+t_3$  is the fusing full open time;  $t_1+t_2$  is the pre-arcing time. Compared with  $t_1$ ,  $t_2$  can be overlooked. Thus, the pre-arcing time actually is the melting time  $t_1$ .

## Simulation model

The topic simulates the pre-arcing thermoelectric coupling temperature field of High-Voltage Current-Limiting Fuse via ANSYS, which is a popular finite element software.

### Unit Selection and Material Properties

This paper analyzes the thermoelectric coupling fusing process. We choose the SOLID69 entity unit and the material under different temperatures are replaced by changeable thermal property values.

### Entity Modeling and Subdivision

This paper adopt the XRNT high-voltage current-limiting fuse with 12kV rated voltage and rated current 200A. The melt is composed of nine parallel silver cords and several long narrow diameters every seven semicircle interval. We take a small part of the melt (a semicircle diameter and a long narrow diameter) to study, and the total length is 18.067 mm., which is shown in Fig.2.

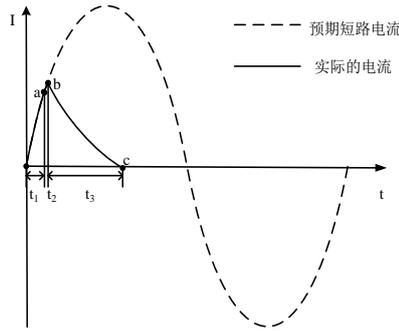


Fig.1 Current waveform of breaking short-circuit of current-limiting fuse



Fig.2 Finite element model of Fuse

### Simulation Results compared with the Manufacturer

#### Compare the Short-circuit Current Simulation results with the manufacturer experimental data

Take 30 times the load short circuit current for example. The initial temperature is 20°C. Zero potential reference surface is set at the right melt side and the left melt side is coupling voltage freedom degree. We load the current at the left melt side. Due to the parallel installed of nine melts, the effective loading current is a sinusoidal alternating current with a value of 6kA/9. The distribution nephogram of melt temperature with loading time 0.01 is showed in Fig.3.

From the left upper corner of the picture we can see that the simulation time is 0.01s, the load step is 51, the step length is 0.2 ms, the highest temperature is 1462°C and the lowest temperature is 245.907°C. Temperature difference is a little bigger because the loading time is rather short and the head conduction is not very obvious. The current density at the narrow necks is largest, so the temperature changes most fast and the heat is conducted to places of low temperature. We can see the highest temperature of the narrow necks at different time points with the time post-processor. As showing in Fig.4, the temperature change rate around  $t = 0.007s$  is changed. This is because the silver melt material parameters vary greatly after passing the melting point temperature.

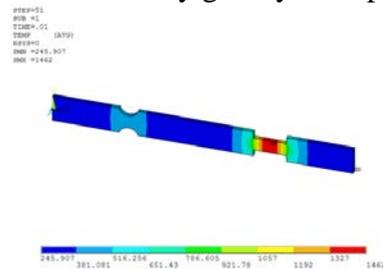


Fig.3 Contours of temperature

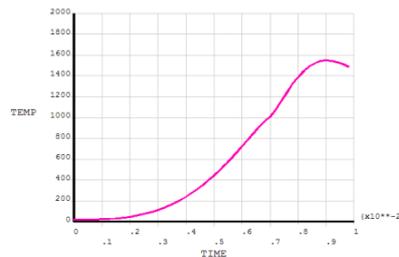


Fig.4 Temperature curve of arcing point

From table.1, when the short circuit time is 0.0068 s, the temperature is 964.871 °C, which is higher than the melting point. The narrow necks begin to arc strike at this time. In other words, the pre-arcing time is 0.0068s.

Table1 List of pre-arc time

TIME (s)	Temperature (°C)
0.66000E-02	905.454
0.68000E-02	964.871
0.70000E-02	1008.85
0.72000E-02	1072.51

The temperature nephogram of 10 times the load short circuit current is depicted in Fig.5. The rectangle narrow diameter is still of the highest temperature. Different from breaking large short-circuit current, the time of current flowing through the melt is 0.18 s, which is much longer than that of large short-circuit current. So the heat of long narrow necks begin to conduct obviously

to low-temperature area and begin to arc strike firstly. We can see the highest temperature of the narrow necks at different time points with the time post-processor. As showing in Fig.6 the temperature continues to rise periodically and after  $t=0.13s$  it goes up faster. This is because the electrical resistivity of liquid silver melt is bigger than that of solid melt, which results in a low capacity of heat transmission.

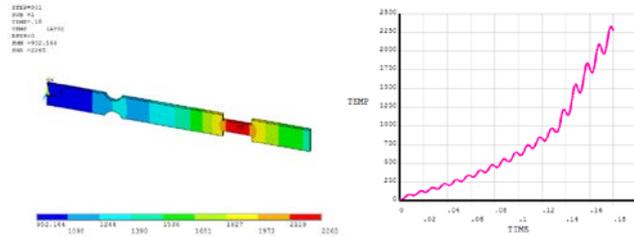


Fig.5 Contours of temperature      Fig.6 Temperature curve of arcing point

From table 2, the pre-arc time of breaking circuit current 2KA is the time point of 2163°C.

Table 2 List of pre-arc time

time (s)	temperature (°C)
0.17500	2144.39
0.17520	2163.78
0.17540	2182.91
0.17560	2201.59

### Manufacture Data contrast Analysis

This paper adopt the high-voltage current-limiting fuse to run simulations, where the rated current is 200A and the simulating failure current is 3 to 35 times of the rating current. The contrast results between manufacture pre-arcing and simulations are showed in Table 3.

Table 3 Pre-arcing time of melting point for the bound

circuit current multiple	prospective short-circuit current/kA	pre-arcing time/ms		relative error/%
		manufacture r	Simulation results	
25	5	13.4	14.4	-7.5
20	4	23.9	24.4	-2.1
15	3	48.8	46.2	5.3
14	2.8	61	55.8	8.5
13	2.6	78	66.6	14.6
12	2.4	108	85.2	21.1
11	2.2	141	105.2	25.4
10	2	180	127.4	29.2
9	1.8	239	165	31.0

The boundary value of above simulation results is the melting time(961.78°C). Compared the manufacture pre-arcing time with the simulation results, we can find that the pre-arcing time is more precise with 13 times circuit current with error range at five percentage. But the pre-arcing time is smaller than that of manufacture under 13 times circuit current. This demonstrates that actual pre-arcing time is longer that simulations. So the overlooked time from melting to arc striking when computing short circuit breaking time should be considered. So considering the phase transition process of pre-arcing time, adopting vaporizing point(961.78°C) as the boundary we compute the modified pre-arcing time, as shown in Table 4.

Table4 Pre-arcing time of boiling point for the bound

circuit current multiple	prospective short-circuit current/kA	pre-arcing time/ms		relative error/%
		manufacturer	Simulation results	
12	2.4	108	114.4	-5.9
11	2.2	141	136.2	3.4
10	2	180	175.2	2.7
9	1.8	239	224.6	6.0

In this paper we propose the idea of adopting the vaporizing point bound as the boundary, which can improve the simulation results and the simulated pre-arcing time is much closer to the accurate values. So when computing the breaking pre-arcing time of high-voltage current-limiting fuse under generally short circuit current, the effects of phase transition should be be considered properly. Fig.7.1 shows the comparison results of manufacture, melting point and adjusted pre-arcing time .

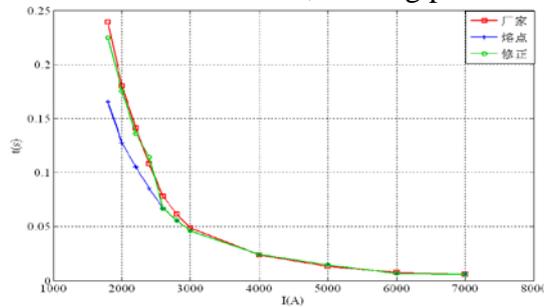


Fig.7 Contrast of pre-arc time

## Conclusion

During the process of breaking current, with different failure current the fuse breaks the current differently in terms of style and performance. When the fuse breaks extra large short circuit fault current(35 times of rating current), the pre-arcing can be considered as adiabatic process completely because the breaking time is very short and the quartz sand and the melt will not conduct and diffuse heat. When under the general short circuit fault current(9-35time of rating current), The heat only diffuse between melts and the pre-arcing time is less than 0.3s, which can be calculated by the finite difference or finite element method. Because the effects of changing temperature on material physical parameters, material physical parameters should be set accordingly. We also find that phase transition has no effect on pre-arcing time and with the decrease of loading current, we need to take the vaporizing point as the boundary to calculate the pre-arcing time.

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