The calculation of the no-load flow field in puffer arcing chamber and the experimental study

WU Jun-hui [1], LI Yan [2], J D Yan 3,WU Ke [2]

[1] State Key Lab of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, 710049, China

[2]Henan Pinggao Electric Co. Ltd., Pingdingshan, 467001, China

[3] Department of Electrical Engineering and Electronics, University of Liverpool, Liverpool, L69 3GJ, UK

Corresponding author: WU Ke Tel.: + 8613903900391 ; fax: +8603753804142

E-mail address: liyanzz@tom.com

Abstract: In order to investigate the effects of SF_6 gas flow filed on the implementation process of circuit breaker, the software of PHOENICS is used in this article to calculate the no-load flow field in puffer arcing chamber. From the simulation, the variations of pressure, velocity and Mach number of SF_6 gas in arcing chamber are derived, and the gas flow in the arcing chamber changes from subsonic to supersonic during the no-load interruption process of circuit breaker is also realized. Except the simulation, the tests of pressure measurement for actual circuit breaker are also researched in this paper to prove the correction of mathematical model. Finally, from the compare of tests and simulation results, it's found that they agree with each other well.

Keywords: flow filed, puffer arcing chamber, pressure measurement

Introduction

Despite the successful development and use in transmission networks of new generations of high voltage circuit breakers, such as auto-expansion and rotary arc circuit breakers, puffer circuit breakers are still exclusively used in the EHV and UHV range owing to their proven reliability and superb interruption capability. The extinguishment of arc in puffer circuit breaker mainly depends on the SF_6 gas flow in the nozzle with a high speed. In high current phase, arc shape is controlled by fast gas flow, meanwhile, in current zero phase, the ionization gas is taken away by fast gas flow, and which is effective for the dielectric recovery between the two contacts [1, 2]. So the study about gas flow in circuit breaker is very important for the geometry design of circuit breaker. It's well-known that flow field in the circuit breaker is very complex and can't be investigated directly, however, the developments of numerical calculation methods and computer capability make it possible for numerical analysis about gas flow in the circuit breaker. In this article, the software of PHOENICS is used to simulate the gas flow in circuit breaker, and the variations of pressure, velocity and Mach number of gas in arcing chamber are also analyzed during the implementation process of circuit breaker. In addition to the numerical simulation, pressure measurement tests are also carried out in the paper. Finally, the simulation results are compared with the experimental results, and the coincidence between them ensures the correctness of calculation.

1. Mathematical model

The arcing chamber of puffer circuit breaker under investigation is rotationally symmetric and the flow is turbulent. The governing equation for the plasma flow can be conveniently written as:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla \bullet (\rho\phi \bar{V}) - \nabla \bullet (\Gamma_\phi \nabla \phi) = S_\phi \tag{1}$$

Where ϕ is the dependent variable that to be solved. The source term S_ϕ and the diffusion coefficient Γ_ϕ are listed in Table 1 where all notations have their conventional meaning. The laminar part of the transport properties (viscosity and thermal conductivity) and electrical conductivity are determined by two thermodynamic variables, enthalpy and pressure. The equation of state and the aforesaid transport properties are tabulated for SF_6 by Frost and Liebermann [3]. Gas density as a function of temperature and pressure is also given in [3]. For temperatures below 300K the equation of state is assumed to have the same form as that for an ideal gas with a gas constant of 56N·M/(kg·K). The laminar viscosity, thermal conductivity and electrical conductivity of SF_6 as a function of pressure and temperature are the same as that used in [4]. Detailed data can be found in the material property subroutines.

Table 1 Expansion of (1) for different solved for variables

Equation	ϕ	Γ	S_ϕ
Mass of mixture	1	0	0
z-momentum	w	$\mu_l + \mu_t$	$-\partial P/\partial z + J_r B_\theta+$ viscous terms
r-momentum	v	$\mu_l + \mu_t$	$-\partial P/\partial r - J_z B_\theta+$ viscous terms
enthalpy	h	$(k_l+k_t)/c_p$	$\sigma E^2 -q +dP/dt +$ viscous dissipation

2. Travel and velocity of circuit breaker

The travel and velocity have great effects to the gas flow in circuit breaker. In order to making the variation of gas flow in arcing chamber derived from simulation mach the actual product, the simulation must be consistent with the actual implementation process of circuit breaker, so the travel and velocity used in simulation is derived from pressure measurement test . In the simulation, some assumptions are also implemented，which are as follow: The moving contact and pressure cylinder are fixed, meanwhile, piston and fixed contact move at the velocity as fig.1 shows.
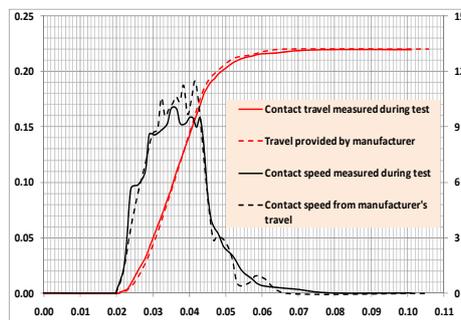

Fig.1 Diagram showing a comparison between the contact travels obtained using on board sensor and that provided by the manufacturer for no-load test with SF_6.

3. Analysis of simulation results

Based on the software of PHEONICS [5], some codes are also compiled in the paper to solve the governing equations. Grid distribution in the contact space of circuit breaker is shown as fig.2.
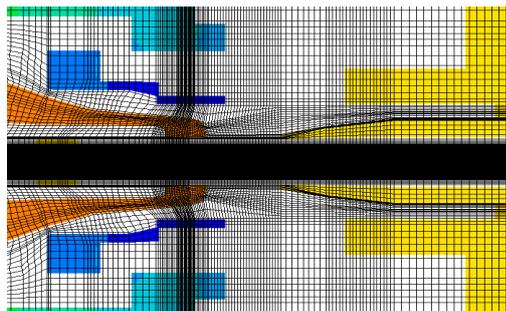

Fig.2 Grid distribution in the contact space of circuit breaker

In the paper, SF_6 is used as working gas and filling pressure is 7bar at 300K. According to the mathematical model, gas flow in the arcing chamber is solved, and the results are shown as fig.3, fig.4, and fig.5.
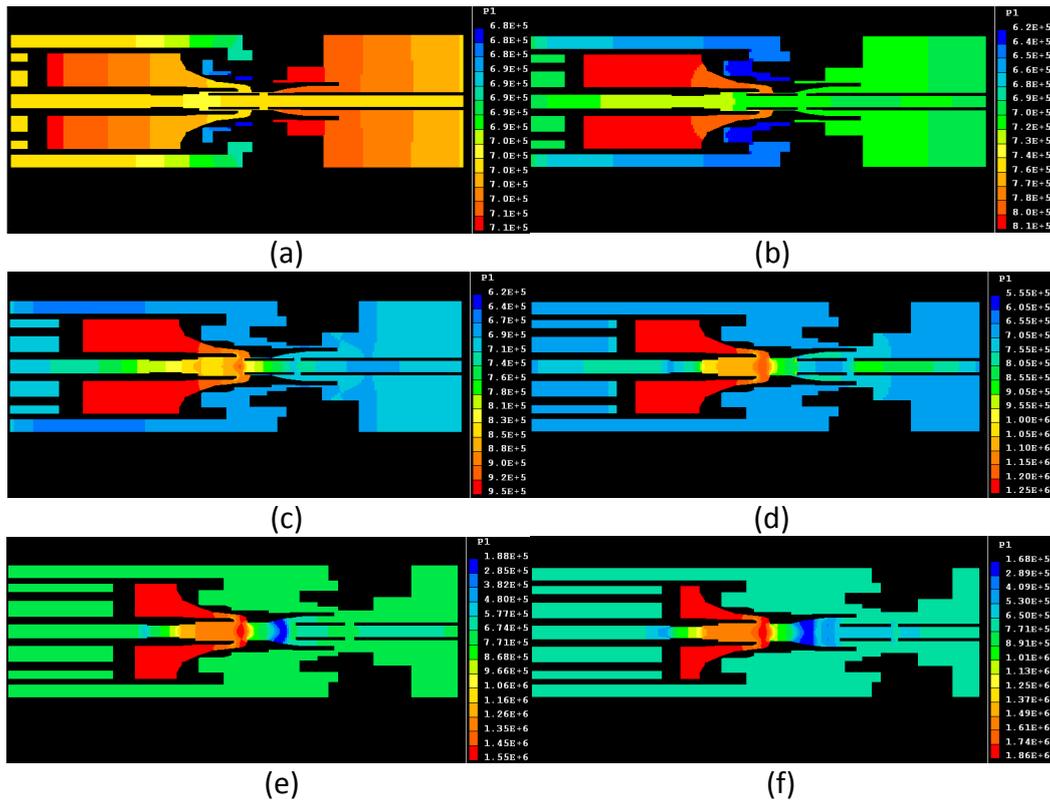

(a) (b) (c) (d) (e) (f)

Fig.3 Changes of pressure field as a function of time with a contact moving away from the other. The instants from (a) to (f) are in millisecond: 21.69, 27.69, 31.69, 37.69, 41.69, and 47.69.

It can be seen from fig.3 that there is no gas change between the arcing chamber and environment before the separation of two contacts, and the pressure in the arcing chamber increases continually under the compress of moving piston.   When the two contacts begin to separate, the largest pressure in the arcing chamber is 0.86MPa. Subsequently, with the increase of velocity, when the fixed contact begins to leave the nozzle throat, the largest pressure is 1.25MPa. It is also shown that there is a low pressure region in the downstream nozzle after the fixed contact has departed from nozzle throat, which is because this region is filled with supersonic flow as shows in fig.5.
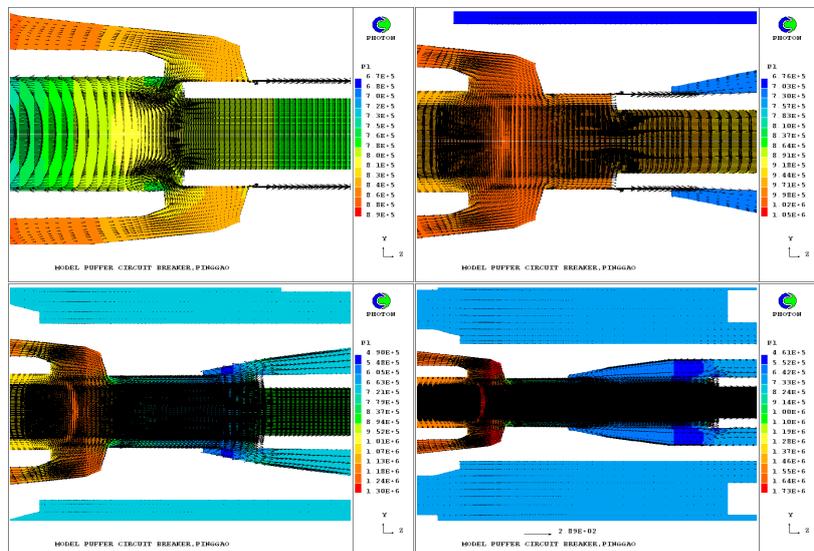

Fig.4 Changes of pressure field as a function of time with a contact moving away from the other
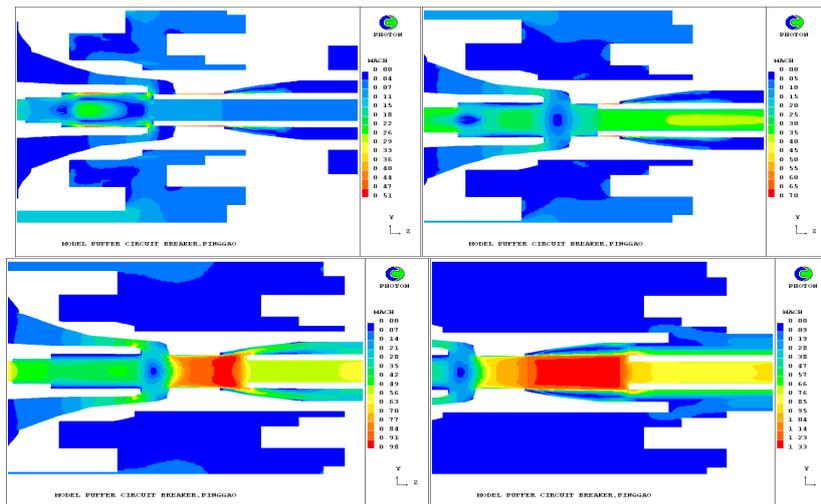
Fig.5 Changes of Mach number as a function of time with a contact moving away from the other

It's described in the fig.4 and fig.5 that the gas in pressure cylinder flows at a lower velocity before a contact separates another, and after they depart from each other, the gas flows in the upstream nozzle will not only blast the arc in the radial direction but also take away arc energy and hot ionization particulates. After the separation of fixed contact and nozzle throat, the subsonic flow in the nozzle becomes supersonic flow. According to the characteristic of supersonic flow in the converging-diverging nozzle, so a lower pressure region occurs in the downstream nozzle.

4. Investigation of pressure measurement tests

Some pressure measurement tests with the actual circuit breaker are carried out to evaluate the simulation results in the paper. In the interruption process of circuit breaker, some important locations are monitored by sensors, such as pressure cylinder, nozzle upstream, nozzle throat, and nozzle downstream. In the tests, the filling gas in the circuit breaker is SF_6 and its initial pressure is 7bar absolute. The comparison between test and simulation results is plotted in fig.6
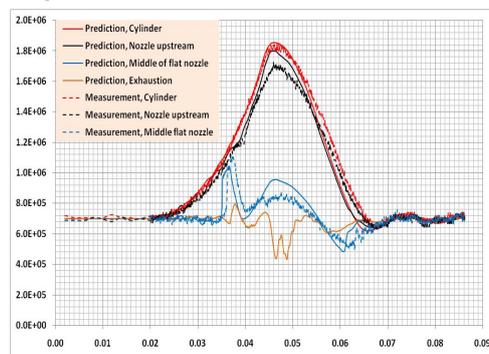

Fig.6. Comparison of predicted and measured pressure variation at three strategically chosen locations in the arcing chamber.

It can be seen from fig.6 that the difference between prediction and measurement is small. Considering the experimental uncertainties, the agreement is rather reasonable, so the correctness of calculation results is confirmed in the paper.

5. Conclusion

1) The variations of gas pressure, velocity and Mach number in arcing chamber are analyzed in this paper, and it's derived from the simulation that gas flow in the arcing chamber changes from subsonic to supersonic during the no-load interruption process of circuit breaker. The nozzle shape takes a great part in the control of gas flow ,so the gas flow in arcing chamber with different nozzle shapes will be studied in the future work.

2) A lot of pressure measurement tests are also carried out here, meanwhile, by comparing tests with simulation, it's found that they agree with each other well, which also ensures the correctness of mathematical model used in the paper.

6. Reference

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[5]. PHOENICS is the name of a commercial CFD package supplied by CHAM which is based at Bakery House, 40 High Street, Wimbledon Village, London, SW19 5AU, UK.