ANALYSIS OF THE VALVES EFFECT ON THE GAS FLOW FIELD AND ARCING PROCESS IN A SELF-BLAST CIRCUIT BREAKER

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ABSTRACT

Valves in self-blast circuit breakers are important parts for the design of arc extinguishing chamber. Aiming to investigate the influence of the valves, the valve motion models are proposed. The gas flow field and the arcing process are simulated with the method of magneto-hydro-dynamics. The average pressure and the force on both sides of the valves are compared. The results show that the closure of the non-return valve around the current peak accelerates the pressure rising in the expansion volume. The opening of the pressure relief valve reduces the overpressure in the compression volume. Under the calculation conditions used in this paper, the non-return valve motioned around 21ms and the pressure relief valve motioned around 24ms.

1. INTRODUCTION

With the advantages of the reduction in operating energy, self-blast circuit breakers have become main competitors to the puffer-type ones applied in the power system. Though the complexity of arc extinguishing chamber structure in self-blast circuit breakers increases the difficulty of modelling and calculating, many valuable results are obtained with the simulations of the computational fluid dynamics. The length of the expansion volume affects the maximum pressure build-up in self-blast circuit breakers [1]. The thermal effect of the pressure rise in the expansion volume is big in the relatively earlier interrupting phase, and the nozzle throat diameter, the length of the nozzle throat influence the pressure generation considerably [2]. Obviously, compared with volumes and nozzle in arc extinguishing chamber, the valves and its effects are discussed less.

In this paper, based on the structure of a 145kV self-blast SF_6 circuit breaker, valve models are proposed for implementing the motions of each valve. The average pressure and the force on both sides of the non-return valve and pressure relief valve are calculated and compared. The influence of the valves on the gas flow field and arcing process are analysed, the motion time of each valve is obtained.

2. CALCULATION MODELS

Arc Model

The method of magneto-hydro-dynamics is also adopted for the simulation. The behaviours of arc and gas flow field can be described by the modified Navier-Stokes equations, considering the Lorentz force, Ohmic heating, radiation loss and nozzle ablation. These equations can be described as in [3, 4] and will not be repeated here.

Structure Model

The calculation structure model of the 145kV self-blast SF_6 circuit breaker is shown in Fig. 1. The refill volume is included for the calculation, except for the expansion and the compression volumes. The locations of the three valves, non-return valve, refill valve and pressure relief valve are given.

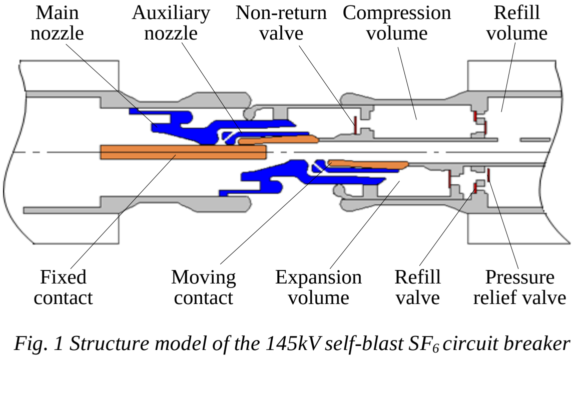

Fig. 1 Structure model of the 145kV self-blast SF_6 circuit breaker

The springs adjacent to the pressure relief valve are not modelled, but effects of their force are considered. Moreover, supposing the circuit breaker is vertical in the simulation, and the moving contact is on the bottom and the fixed contact is on top. With the help of gravity and spring force, the three valves are all closed initially.

Valve Models

Fig. 2 shows the valve models and the around mesh. The region A represents the location of the valves open, while the region B represents the location of the valves closed. As there are springs adjacent to the pressure relief valve, the valve cannot open or close abruptly, so more locations are given between region A and region B, which is implemented through the technology of sliding and dynamic mesh.

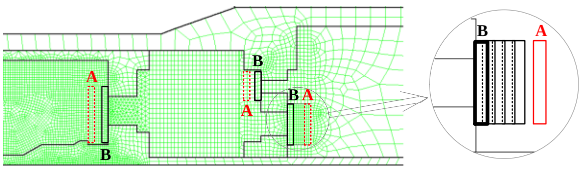

Fig. 2 The valve models and the around mesh

Whether the valves move or not is attributed to the total force on each valve. When adding the gravity to the valve side surface, the total force of each valve is then the force difference between the sides of each valve. A criterion for valve motion can be expressed as

$$P_F = \frac{F_o - F_c}{F_c} \times 100\% \quad (1)$$

Where, P_F is the percent, F_o is the force for opening the valve and F_c is the force for closing the valve. In addition, a threshold valve C_{th} is introduced. If $P_F > C_{th}$ then, valve moves to open; if $P_F < -C_{th}$ then, valve moves to close; beside the above two conditions, valve does not move. The threshold valve C_{th} in this paper is chosen as 2%.

3. RESULTS AND ANALYSIS

In this calculation, the filling gas pressure inside the arc extinguishing chamber is 0.6MPa and the initial temperature is 300K, the average speed of the moving parts is 5m/s during arcing process, the effective value of the current is 30kA and its waveform can be seen in the curves next. When the mechanism starts to move, the non-return valve will open affected by the force of inertia and the force generated by gas flow.

Contours of gas temperature and pressure

Fig. 3 shows the contours of the gas temperature at some instants. At 15.6ms, the current is lower 1.3kA, the arc radius is small and no backflow emerges, the non-return valve is open and the other two valves are closed. At 21.5ms, the current achieves 41.7kA, arc fills the nozzle region and backflow goes into the expansion volume. The valves are all closed. At 25.0ms, the current reduces to 7.0kA, backflow disappears, but hot gas still can be seen in the expansion volume and it appears to be a vortex due to the closure of the non-return valve mostly. The pressure relief valve is open into a large gap at the time.

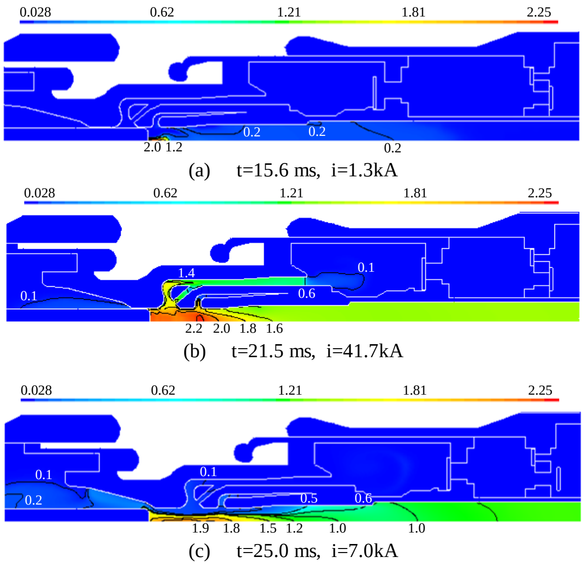

Fig. 3 Contours of gas temperature (10^4K)

Fig. 4 shows the contours of the gas pressure at some instants.

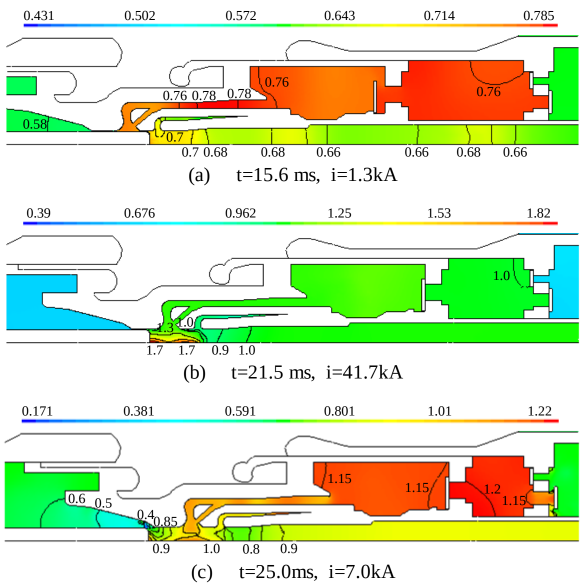

Fig. 4 Contours of gas pressure (MPa)

It can be seen that the effects of valves to the distributions of gas pressure are obvious. At 15.6ms, the opening of the non-return valve leads the gas to flow from the compression volume into the expansion volume; meanwhile, the valve also has some restrictions for gas flow and pressure wave. At 21.5ms, higher pressure locates in the arc region. The non-return valve is closed and the pressure difference between the expansion and compression volumes is small. At 25.0ms, the pressure in the compression volume is larger than that in the expansion volume. Because of the closure of the non-return valve, gas flow in the two volumes cannot mix. Overpressure in the compression volume leads to the open of the pressure relief valve to relief gas flow. As the refill valve closes all the time during the arcing process, it is not analysed in the followings.

Comparisons of the average pressure

Fig. 5 and Fig.6 show the comparisons of the average pressure on both sides of the non-return and the pressure relief valves varying with the time.

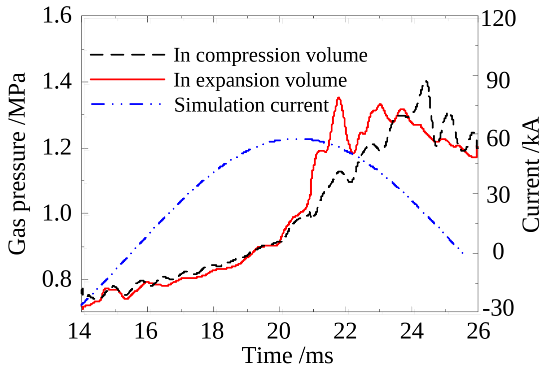

Fig. 5 Comparisons of the average pressure on both sides of the non-return valve

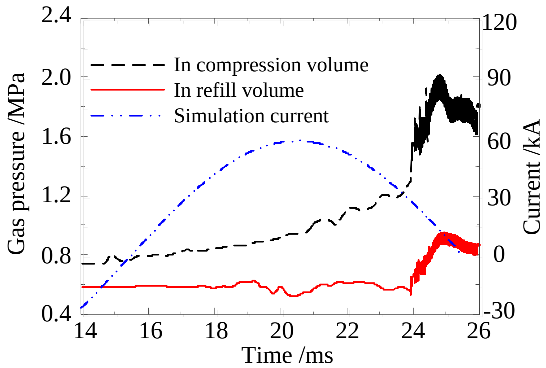

Fig. 6 Comparisons of the average pressure on both sides of the pressure relief valve

It indicates from Fig. 5 that the values of the average gas pressure in the expansion and compression volumes are all rising, and the difference is small before non-return valve is closed. After that, non-return valve moves to close around 21ms, the pressure rises faster in the expansion volume than that in the compression one, because of the hot gas backflow when the current approaches to the peak. Around 23.5ms, gas pressure in the compression volume becomes higher, but it cannot affect the gas pressure in the expansion volume, because of the closure of the non-return valve. It indicates from Fig. 6 that the values of gas pressure in the refill volume changes around 0.6MPa before about 24ms, which is the time of the pressure relief valve starting to open. The curves of gas pressure oscillate frequently with the motion of pressure relief valve, which reveals the reciprocating motion process of the pressure relief valve.

Comparisons of the average force

Fig. 7 and Fig. 8 show the comparisons of the average force on both sides of the non-return and the percent of the force difference, respectively. The valve gravity is considered and added to the force in the expansion volume.

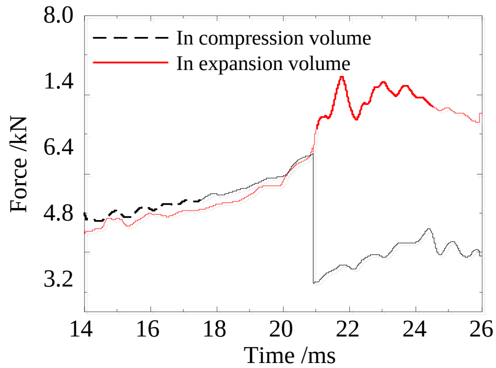

Fig. 7 Comparisons of the average force on both sides of the non-return valve

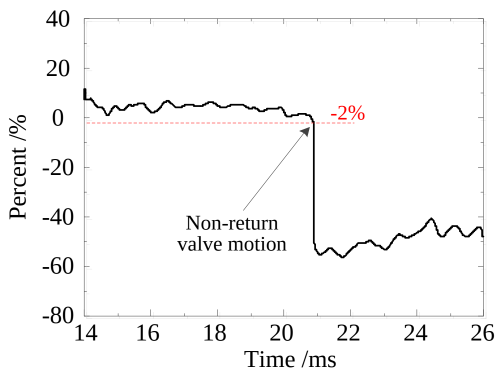

Fig. 8 Percent of the force difference of the non-return valve

It can be seen from Fig. 7, the force of non-return valve in the expansion volume is smaller than that in the compression volume before about

21ms. When the non-return valve closes, the force in the compression volume goes down abruptly. This is attributed to the area reduction of non-return valve in the compression volume. From Fig. 8, it can be seen that the percent of force difference between the two sides of the non-return valve gets down below -2%, which means that the non-return valve moves from open state to closed one. It can also be found that after the non-return valve closed, the force in the expansion volume is much higher than the force in the compression volume all the time and the percent of the force difference is still lower than -2%. This can also describe why non-return valve does not open again after 23.5ms.

Fig. 9 and Fig. 10 show the comparisons of the average force on both sides of the pressure relief valve and the percent of the force difference, respectively. The valve gravity is added to the force in the expression volume and the force of the springs is added to the force in the refill volume. The initial force of the springs is 414N.

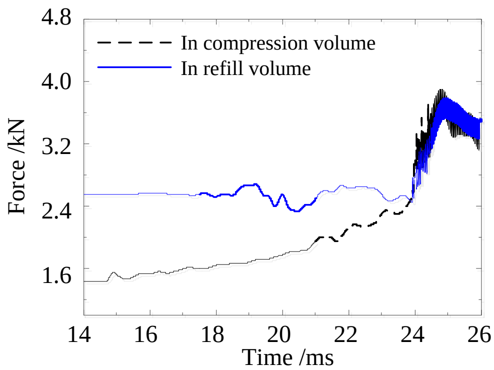

Fig. 9 Comparisons of the average force on both sides of the pressure relief valve

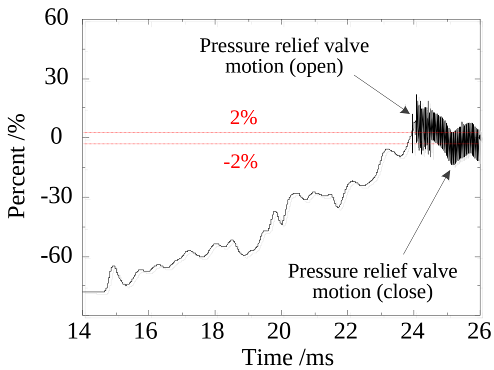

Fig. 10 Percent of the force difference of the pressure relief valve

It can be seen from Fig. 9, the force in refill volume is larger than that in compression volume before about 24ms. The total force in refill volume is about 2550N. The total force in compression volume keeps increasing with the rising of gas pressure. After the pressure relief open, the oscillation of the force is shown. From the percent of force difference in Fig. 10, it can be seen that the pressure relief valve moving towards open or closed is judged by the valve motion criterion. With the help of the threshold valve 2%, the movement of the pressure relief valve can be implemented and the continuous motions of the valve are given with the interaction of the gas flow field.

4. CONCLUSIONS

The motions of valves and their effects on the gas flow field are complex processes. By proposing the valve motion models in this paper, the characteristics of gas flow field with valve motions are obtained using the computational fluid dynamic simulation. It can be concluded that under the calculation conditions, the non-return valve closes at about 21ms around the current peak and the pressure relief valve starts to motion at about 24ms. The closure of the non-return valve accelerates the pressure rising in the expansion volume and the opening of the pressure relief valve reduces the overpressure in the compression volume. The reciprocating motion processes of the pressure relief valve can be revealed from the curves.

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