MATHEMATICAL SIMULATION OF BREAKING CHARACTERISTICS OF AN SF6 PUFFER INTERRUPTER WITH A HYDRAULIC OPERATING MECHANISM

X. Zhang*  Z.Y. Ma  G. Wang

Department of Electrical Engineering,
Xi'an Jiaotong University, Xi'an China

ABSTRACT

The characteristics of the hydraulic operating mechanism are simulated precisely and simply through the apply of black-box based on a given breaking velocity without current. Therefore a new method set up to calculate the breaking velocity with current. The method is suitable for various of parameters of the operating mechanism, the interrupter and the experimental condition.

KEYWORDS

puffer circuit breaker, opening velocity, hydraulic operating mechanism

PREDICTION

A circuit breaker is capable of interrupting when the mechanism can meet the demands for the breakers motion. The design of the mechanism is so decisive for the circuit breaker that the interaction between the two subsystems can be investigated. The investigation involves not only mechanical kinetics and hydrodynamics, but also thermodynamics under the influence of current. Amount of equations contain empirical errors, therefore a new method will be found to investigate the behavior of the puffer circuit breaker with a hydraulic operating mechanism with current.

* Present Address: Xi'an High Voltage Apparatus Research Institute.

DESCRIPTION OF A HYDRAULIC OPERATING MECHANISM

In the process of interruption, the piston of the operating cylinder is exerted by the following, such as hydraulic operating force, compression force, buffer force, frictional force.

Hydraulic Operating Force

Pressure difference of the piston's both sides (as shown in Fig. 1), causes hydraulic operating force $F_p$:

$$F_p = P_o A_o - P_i A_i$$ (1)

$$P_o = P_{o0} - \Delta P_o$$ (2)

$$P_i = P_{i0} - \Delta P_i$$ (3)

where:

$P_o$: high pressure in the operating cylinder

$P_i$: low pressure in the operating cylinder

Figure 1
cylinder

\[ A_s : \text{area at the high pressure sides in the cylinder} \]

\[ A_b : \text{area at the low pressure sides in the cylinder} \]

\[ P_{sa} : \text{pressure in the accumulator} \]

\[ P_m : \text{pressure in the oil tank} \]

\[ \Delta P_s : \text{pressure loss from the accumulator to the cylinder} \]

\[ \Delta P_b : \text{pressure loss from the cylinder to the oil tank} \]

Equations (1)–(3) need that a few problems are demonstrated as following:

1. Pressure change in accumulator
   Heat insulation is taken consideration during the interruption. Usually, the accumulator is designed that the pressure change is so small after a process of interruption that it may be neglected.

2. Pressure change in the auxiliary oil tank
   The pressure in the auxiliary oil tank is equal to atmospheric pressure. The pressure change is because that the oil flow into the auxiliary oil tank from outside, but it is small to change with oil flowing from the auxiliary oil tank to the main oil tank.

3. Pressure loss
   By Bernoulli's equation, the pressure losses during the distance of \( l \) may be described as:

\[ \Delta P_l = \sum K_j^2 \frac{\zeta_j^2 y_j^2}{2g} \]  

(4)

\( u \): velocity of the piston in the cylinder

\( K_j \): area coefficient at the point of \( j \) during the distance of \( j \)

\( \zeta_j \): coefficient of the pressure loss

Furthermore,

\[ F_r = (P_s A_s - P_m A_b) \]

\[ \left( A_s \sum K_j^2 \frac{\zeta_j y_j}{2g} + A_b \sum K_j^2 \frac{\zeta_j y_j}{2g} \right) u^2 \]  

(5)

The equation (5) leads to the complex calculation mentioned above, thus it is necessary to simplify the equation.

Let

\[ D = P_s A_s - P_m A_b \]

(6)

\[ C = A_s \sum K_j^2 \frac{\zeta_j y_j}{2g} + A_b \sum K_j^2 \frac{\zeta_j y_j}{2g} \]

(7)

\( D \) connecting with the temporal pressure and atmospheric pressure, is called the prediction force of the accumulator, it is considered a constant in the process of opening operation.

\( \zeta_j, K_j \) connecting with the construction of the hydraulic pipe and valve at the point of \( j \), so \( C \) is called the coefficient of the loss in the hydraulic pipe, and it is only a function of the travel which is described \( C \). From this, the hydraulic force is given by the following simply equation

\[ F_r = D + Cu^2 \]

(8)

The Buffer Force

Fig. 2 shows the picture of the hydraulic buffer.

![Figure 2](image)

During the interruption, the rod is drawn to the left. When the rod head is going to enter into the buffer hole, the pressure at the low pressure side is raised in the cylinder, and the pressure difference between two sides of the piston is decrease. The buffer force is derived from

\[ F_b = B \times u \]

(9)

\[ B = \frac{3 \pi \eta l_A \cdot D_s \left( D_s^2 - D_{ls}^2 \right)}{4 \pi^3} \]

(10)

\( B \) is the coefficient that is only connection with the construction of the buffer.
The Compression Force of chamber

The electric field strength $E$ and area $A$ of the arc column are critical to define the energy supply and the moving contact cylinder. The properties of the area and the electrical field strength of the arc column are simulated approximately in consideration of radiation and enthalpy, and the pressure and temperature of moving contact cylinder.[3]

In the upstream,

$$A = \frac{\alpha_s |l| \times 10^{-3}}{\sigma (122.5 - 17.5|g/|l|) \sqrt{P}}$$  \hspace{1cm} (11)

$$E = \frac{|l|}{100 \sigma A}$$  \hspace{1cm} (12)

$\alpha_s$: radiation coefficient
$\sigma$: conductance

while $A$ is bigger than the area of nozzle throat $A_0$, let $A = A_0$.

The main equation to solve the compression force $F$, of the moving contact cylinder is:

$$Q \frac{dT}{dt} + F_p \mu dt - dmR = mC \frac{dT}{dt}$$  \hspace{1cm} (13)

where: $T$—gas temperature
$Q$—arc energy
$m$—gas mass
$C$, —specific heat of fixed volume

THE ANALYSIS OF A HYDRAULIC MECHANISM

The breaking velocity with current is the important property of a mechanism, and the number of expensive measurements is needed while the experiment without current is convenient, and properties of the mechanism can be reflected by the breaking velocity with current. It is an assumption that the hydraulic drive is identified as a whole. Either the experimental velocity or calculated velocity without current is taken as the input, the output is the breaking velocity with current.

Assuming that the opening velocity without current $u_i = u_i(t)$ is known under the given construction of the breaker and experimental condition.

Replacing the frictional coefficient of $\eta$, for $F$, the momentum equation for $n$—breakers of the circuit breaker is given

$$D + Cu_i^2 - nF_p - Bu_i(x) = \frac{\sum M}{\eta} \frac{du_i}{dt}$$  \hspace{1cm} (14)

Here,

$$I(x) = \begin{cases} 0 & X < S_a, \\ 1 & X \geq S_a \end{cases}$$  \hspace{1cm} (15)

$S_a$: the buffer position which the piston rod is going to enter into the buffer.

The parameters of $D$, $C$ are independent of breaking current, by which the relationship between the breaking velocity and opening velocity is obtained.

$$D = \frac{\sum M}{\eta} \frac{du_i}{dt}$$  \hspace{1cm} (16)

$$C = \left[ \frac{\sum M}{\eta} \frac{du_i}{dt} - D + nF_p - B \cdot u_i(t) \right] / u_i^2$$  \hspace{1cm} (17)

The initial condition is $u_i \big|_{t=-\infty} = 0$.

The breaking condition is

$$i(t) = \sqrt{2} I sin (\omega t + \Phi)$$  \hspace{1cm} (18)

Where $I$ is the breaking current and $\Phi$ is the arcing phase angle. So $u_2(t)$ can be solved by above equations.

If parameters of the chamber and mechanism, for instance the pressure in the accumulator, are altered, this simulation method can be also applied.

APPLICATION

Fig. 3 shows an example the curves of the opening velocity plotted over the time $t$, and a comparison of the calculated and measured breaking velocity for Type LW6-550 circuit breaker under the given a current of 63.5kA.
From these the calculated curve is in good agreement for the measured one.

![Graph showing measured and calculated velocities](image)

**Figure 3**

1. measured opening velocity
2. measured breaking velocity
3. calculated breaking velocity

**CONCLUSIONS**

The breaking characteristics of the hydraulic operating mechanism are simulated precisely and simply through the approach of black box based on an understood opening velocity without current, therefore a new method is set up to calculate the breaking velocity with current. The breaking velocity with current is lower than the opening velocity without current, so that the effect of current on hydraulic mechanism must be considered.

**REFERENCES**


