Contactor Parameter Computation and Analysis of Air Circuit Breaker With Permanent Magnet Actuator

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***Abstract*— Contactors are the most critical component of an air circuit breaker (ACB) which is required universally to switch on or off the power supply. This paper reports the design of a new type of contactor with double breakers for an ACB using permanent magnet actuator (PMA). Three-dimensional (3-D) finite element method (FEM) is employed to compute the electro-dynamic repulsion force, including the Holms force and Lorenz force acting on static and movable contacts. The repulsion force for different number of contacts is computed and it is found that the repulsion force increases gradually from the outer contact to the inner contact until it reaches a maximum. The contact of the double breaker is subsequently manufactured according to the predicted design to validate the simulation.**

I. Introduction

Circuit breaker plays an important role in power system. In order to improve the circuit breaker reliability, new concept circuit breakers with permanent magnet actuator (PMA) are being developed [1]-[4]. The proposed PMA offers many advantages such as low component counts and high reliability when compared with conventional spring operated circuit breaker (SOCB). Both vacuum circuit breaker (VCB) and air circuit breaker (ACB) can exploit PMA efficiently and effectively.

Compared with conventional spring circuit breakers, permanent magnet circuit breakers have a lot more issues to address even though the latter are structurally more simple. Indeed, contactor parameter computation is one of the critical factors in the design of ACB structure. A method to compute the temperature of the ACB with spring actuator has also been reported [5]. In this paper, a new type of contact with double breakers is proposed for the ACB with permanent magnet actuator (PMA). 3-D finite element method (FEM) is employed to compute the electro-dynamic forces between the static and movable contacts. The computed results indicate that the repulsion force do increase gradually from the outer contact to inner contact until a maximum is reached. It then reduces slightly thereafter. The computation of the repulsion force for contacts arranged with permanent magnets will be described in details in the full paper. Lastly, the contacts of the double breaker are manufactured according to the analyzed results for validation and comparison.

II. Mathematics Model and Contactor Assembly

The static magnetic field method is used to compute the electro-dynamic repulsion force. Since eddy current has little effect on the electro-dynamic repulsion force, the static magnet field equation can be employed to solve current density and flux density distribution. The vector potential $\boldsymbol{T}$ is used to calculate the current density

$$\boldsymbol{J} = \nabla \times \boldsymbol{T} \tag{1}$$

where $\boldsymbol{T}$ satisfies the following governing equation

$$\nabla \times \left(\frac{1}{\sigma} \nabla \times \boldsymbol{T} \right) = 0 \tag{2}$$

The current constrain condition is

$$\oint_s \boldsymbol{T} \cdot dl = \boldsymbol{I} \tag{3}$$

If the current density $\boldsymbol{J}$ is obtained, vector magnetic potential $\boldsymbol{A}$ is employed to depict the flux density $\boldsymbol{B}$

$$\boldsymbol{B} = \nabla \times \boldsymbol{A} \tag{4}$$

The whole area vector magnetic potential satisfies the following governing equation

$$\nabla \times \left(\frac{1}{\mu} \nabla \times \boldsymbol{A} \right) = \boldsymbol{J} \tag{5}$$

The contact force density f is calculated based on the relationships of current, magnetic field and electromagnetic force

$$F = \int_V f dV = \int_V J \times B dV \tag{6}$$

where V is the contact volume. The electro-dynamic repulsion force of the contacts is computed using the electrical bridge model. The Holms force and Lorenz force acting on the contactor are computed using finite element method (FEM).

Fig. 1 shows the proposed contact for the ACB with PMA. The mechanical system mainly consists of the PMA, a rotating shaft, a cam and a movable contact.

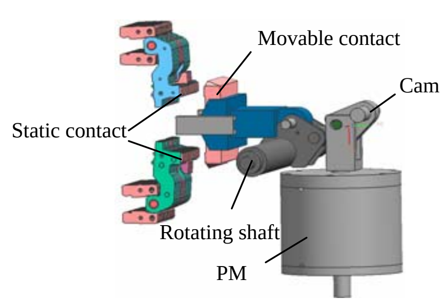


Fig. 1. Assembly of the contact located on the ACB

III. Finite Element Analysis

Because of symmetry, only a quarter model as shown in Fig. 2 is needed to represent the complete unit. The contact has a double breaker structure which includes a static contact and a movable contact. 3-D FEM is employed to analyze the behavior of the contacts. Fig. 2 shows the meshes of the quarter model. The element number is 46539 and there are 53925 nodes. Fig. 3 shows the current density distribution with parallel and single contacts. It is noted that the maximum current density distribution is located at the contacts point.

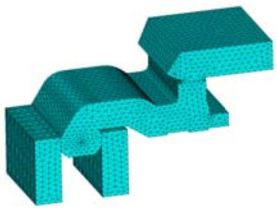
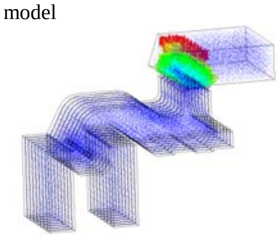
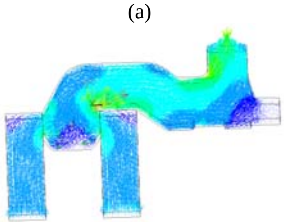


Fig. 2. Meshes of 1/4 model



(a)



(b)

Fig. 3. Current density distribution (a) parallel contacts (b) single contact

Fig.4 shows the magnetic field distribution. It can be seen that the maximum magnetic field distribution is also located on the contact point.

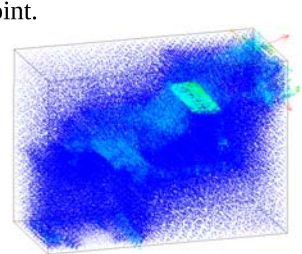


Fig. 4. Magnetic field distribution

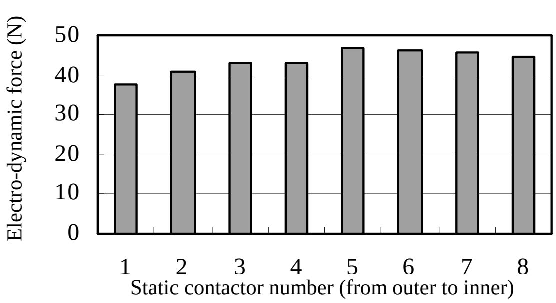


Fig. 5. Comparison of electro-dynamic repulsion force of different static contactors

IV. Analysis and Discussion

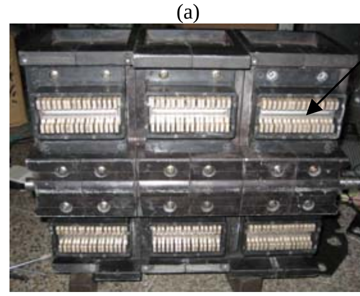
Fig.5 shows the computed results of the electro-dynamic repulsion force. It can be observed that the repulsion force increase as the static contact number increases from outer to inner. The maximum absolute increase in value is 23.3%. Such result shows that the inner repulsion force is higher than that of the outer repulsion force due to the special ACB design being investigated in this study. Fig. 6 presents the contacts being incorporated into the ACB. The repulsion force for contacts alongside with permanent magnet will be discussed in details in the full paper.

V. Conclusion

3-D FEM is used successfully to compute the electro-dynamic forces of double breaker contacts in an ACB with PMA. The repulsion force for the different contacts is computed. The computed results show that the repulsion force increases gradually from the outer contactor to the inner one until the force reaches a maximum. The maximum absolute increase in force reaches 23.3% when compared with the electro-dynamic forces acting on the inner-most contact. Finally, the contacts for the double breaker is manufactured according to the predicted design to validate the simulation findings.

(a)

contact



(b)

Fig. 6. Prototype and contactors (a) Top overview (b) Back overview

Acknowledgment

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VI. References

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