Improved High-speed Permanent Magnet Actuator With Asymmetrical Structure for Extra High Voltage Vacuum Circuit Breaker

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***Abstract* — This paper proposes an improved high-speed permanent magnet actuator (IHSPMA) with asymmetrical structure for extra high voltage vacuum circuit breaker. The IHSPMA includes mainly an eddy current repulsion force actuator and permanent magnets (PM). The structural saliency of IHSPMA is described and its control principle is presented in details. Finite element method is used to compute the electro-magnet field of the IHSPMA.**

I. Introduction

In recent years, smart grid is being developed to meet the needs of increasingly high power demand in many parts of the world in a sustainable manner. There is a tendency to transmit power at ultra-high voltages in a smart grid. For extra high voltage circuit breakers, there are two key design factors which are, namely, the arc extinguishing media and actuator, which must be addressed carefully. Hitherto, either SF_6 or vacuum are commonly used as the arc extinguishing media. However the decomposed product of SF_6 by electric arc is poisonous, which pollutes air and produces greenhouse effect. Therefore, the vacuum is considered as the best arc extinguishing media. However, common actuators in the market use either spring actuator or permanent magnet actuator [1]-[4]. Recently, there are some research studies on high speed actuators [5]-[8], nonetheless studies on extra high voltage circuit breaker is still in their infancy. In this paper, an improved high-speed permanent magnet actuator (IHSPMA) with asymmetrical structure for extra high voltage vacuum circuit breaker is reported.

II. Structure Description

A. Traditional Permanent Magnet Actuator

Permanent magnet (PM) actuator as shown in Fig. 1 has much less components than their spring counterparts [1]-[3]. It mainly includes the static iron, moving iron, making coil, breaking coil and PM and has a symmetrical structure.

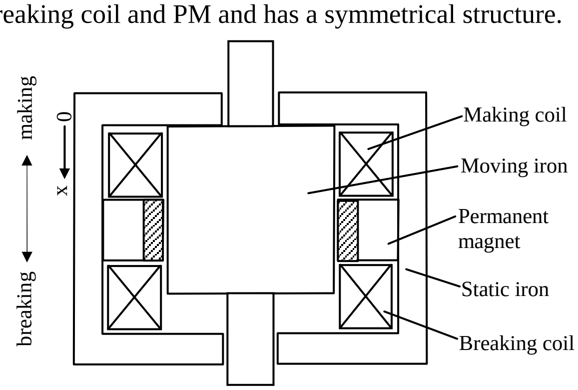


Fig. 1. Traditional permanent magnet actuator

B. Proposed Permanent Magnet Actuator

Fig. 2 shows the forces acting on the circuit breaker (CB). Curve ‘a’ is the spring anti-force of the CB. Due to the symmetrical structure of the actuator, the curve ‘b’ due to the PM is symmetrical along the x axis. Since there is no need to provide a very high force to maintain the holding status of the CB at the open position, it is more preferable to decrease the holding force from curve ‘b’ to curve ‘c’ as shown in Fig. 2 in order to make the CB more compact. Such changes can further decrease the operation power of the CB as well as reducing its closing speed.

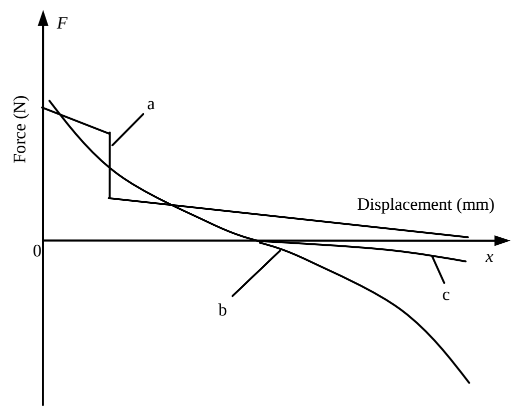


Fig. 2. Forces acting on the circuit breaker without current (a) Spring anti-force (b) Permanent magnet force (c) Improved permanent magnet force

Fig. 3 shows the schematic of an improved permanent magnet actuator with asymmetrical structure with the holding characteristics of curve ‘c’ of Fig. 2. The improved permanent magnet actuator (PMA) mainly includes the eddy current actuator and an asymmetrical PMA.

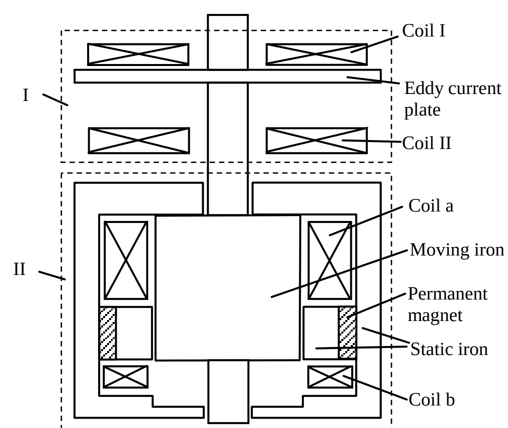


Fig. 3. The improved permanent magnet actuator

III. CONTROL PRINCIPLE

Fig. 4 shows the control principles including the making and breaking procedures. Table I depicts the state of the switches. When making, coil ‘a’ is supplied with positive current and coil b is supplied with negative current, and the moving iron is driven upward. At the same time, as coil II is supplied with an impulse current, eddy current will be induced in eddy current plate. Repulsion force is generated between the eddy current plate and coil II during the making process. The breaking procedure is reversed when compared to the making procedure.

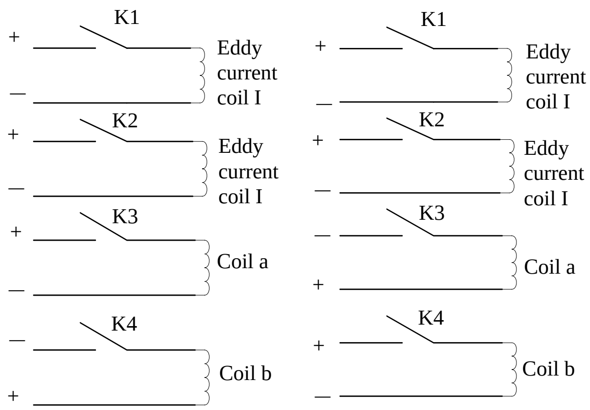


Fig. 4 Control principle (a) making procedure (b) breaking procedure

TABLE I
THE CONTACT STATE OF THE MAKING OPERATION AND BREAKING OPERATION

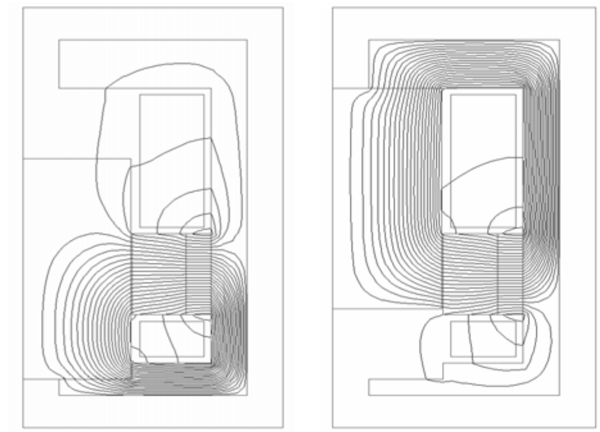
Switch	Making operation	Breaking operation
K1	OFF	ON
K2	ON	OFF
K3	ON	ON
K4	ON	ON

IV. MAGNETIC FIELD FINITE ELEMENT ANALYSIS

The nonlinear magnetic field of the PM actuator can be analyzed using finite element method (FEM). The boundary problem is described as follows:

$$\begin{cases} \left.\begin{array}{l} \nabla\times\frac{1}{\mu}\nabla\times\boldsymbol{A}-\nabla\frac{1}{\mu_0}\nabla\cdot\boldsymbol{A}+\sigma\left(\frac{\partial\boldsymbol{A}}{\partial t}+\nabla V\right)=0 \\ \nabla\cdot\sigma\left(\frac{\partial\boldsymbol{A}}{\partial t}+\nabla V\right)=0 \end{array}\right\} & in\ \ \Omega_1 \\ \nabla\times\frac{1}{\mu}\nabla\times\boldsymbol{A}-\nabla\frac{1}{\mu}\nabla\cdot\boldsymbol{A}=\boldsymbol{J}_s & in\ \ \Omega_2 \\ \nabla\times\frac{1}{\mu}\left(\nabla\times\boldsymbol{A}-\boldsymbol{B}_r\right)=0 & in\ \ \Omega_{\mathrm{m}} \\ \left.\begin{array}{l} \boldsymbol{A}\times\boldsymbol{n}=0 \\ \frac{1}{\mu_0}\nabla\cdot\boldsymbol{A}=0 \end{array}\right\} & S_\Omega \end{cases} \quad (1)$$

where; $\boldsymbol{A}$ is the magnetic vector potential; $\boldsymbol{J}_s$ is the current density of the exciting current; Ω_1 denotes the eddy current region; Ω_2 denotes the non-eddy current region; Ω_m denotes the PM region; S_Ω is the boundary condition. Fig. 5(a) and 5(b) shows the flux distributions without exciting current at the open and closed positions, respectively.



(a) (b)

Fig. 5. Flux distributions without exciting current (a) open position (b) closed position

ACKNOWLEDGMENT

This work was jointly supported by the NSF of Jiangsu Province (BK2010197), the NSFC (50907007), the SRFDP (20090092120041), the Fundamental Research Funds of the Southeast University (3216000503, 3216000102).

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