Optimization Design of a Permanent Magnet Actuator for 126kV Vacuum Circuit Breaker

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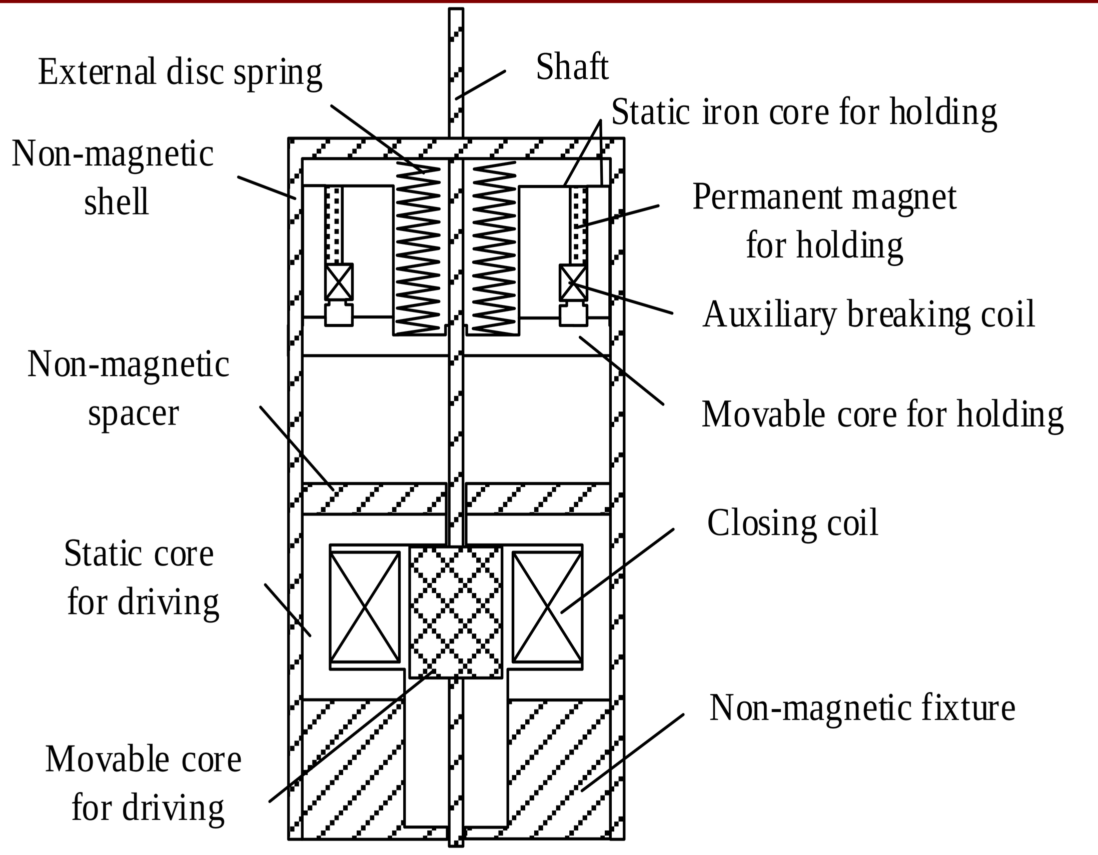
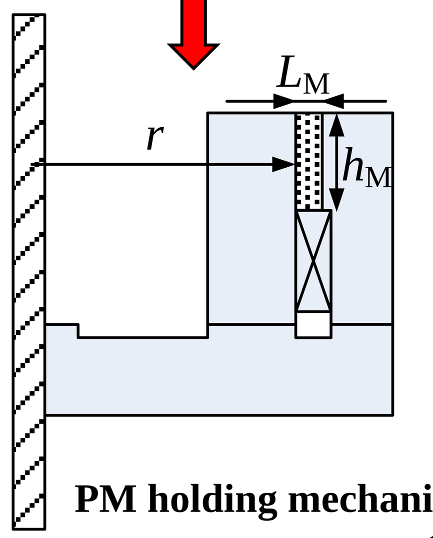
Introduction

- **Background**
  - **Vacuum circuit breaker (VCB)**
    VCBs have been widely used in the distribution voltage levels of 3.6~40.5 kV due to their characteristics of environmentally friendly, maintenance-free and high breaking performance. Now their applications are extending to higher transmission voltage levels such as 126kV level in order to gradually replace SF_6 circuit breakers whose insulation and arc extinguishing gas is harmful to environment.
  - **Permanent magnet actuator (PMA)**
    PMAs have advantages of high controllability and high reliability, which make them be widely used as the operating mechanism of medium-voltage VCBs. Unlike the applications in medium-voltage situations, the PMA used in high-voltage power system has a much longer stroke and requires a much higher velocity, which limits the application of traditional PMA in high-voltage field.
- **Contribution of this paper**
  - ✓ **A novel mono-stable PMA** ⟹ Suitable for high voltage VCB
  - ✓ **A multi-step optimization method** ⟹ To decrease the optimization time and get a global optimal solution

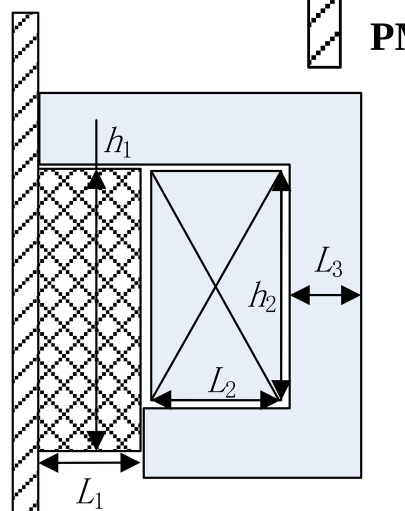
Topology Structure



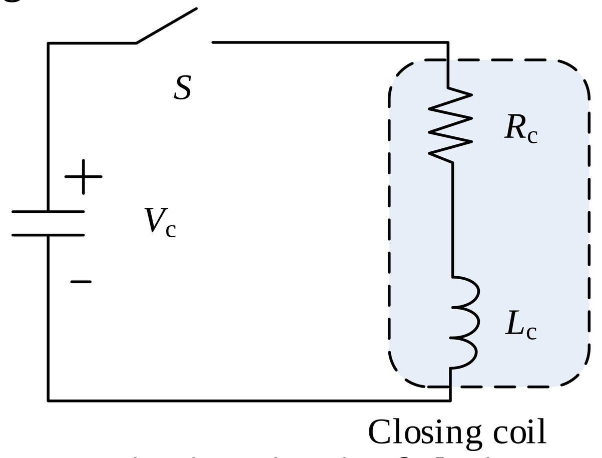
Structure of the proposed PMA



PM holding mechanism

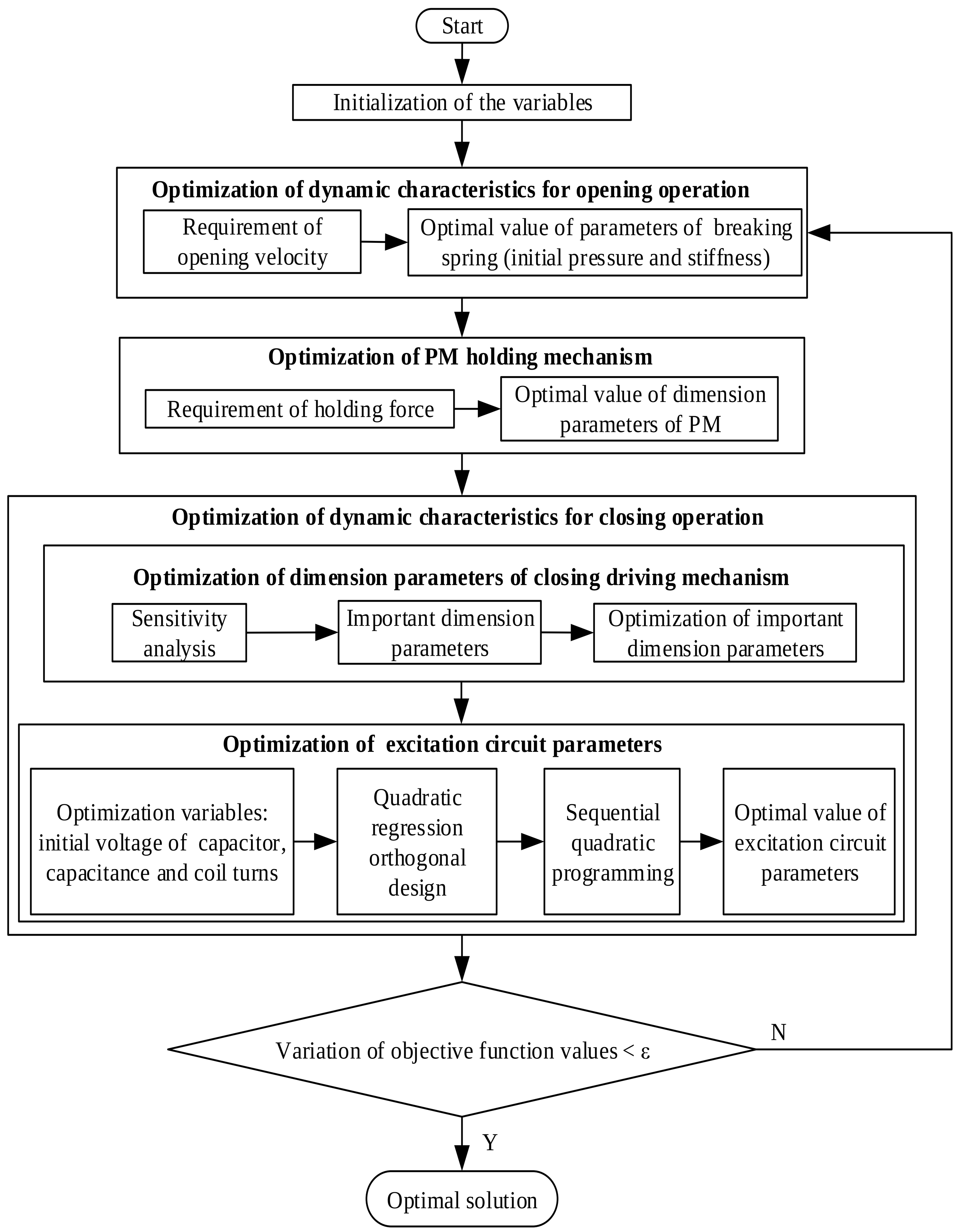


Mechanical part of closing driving mechanism



Excitation circuit of closing driving mechanism

Optimization Flowchart

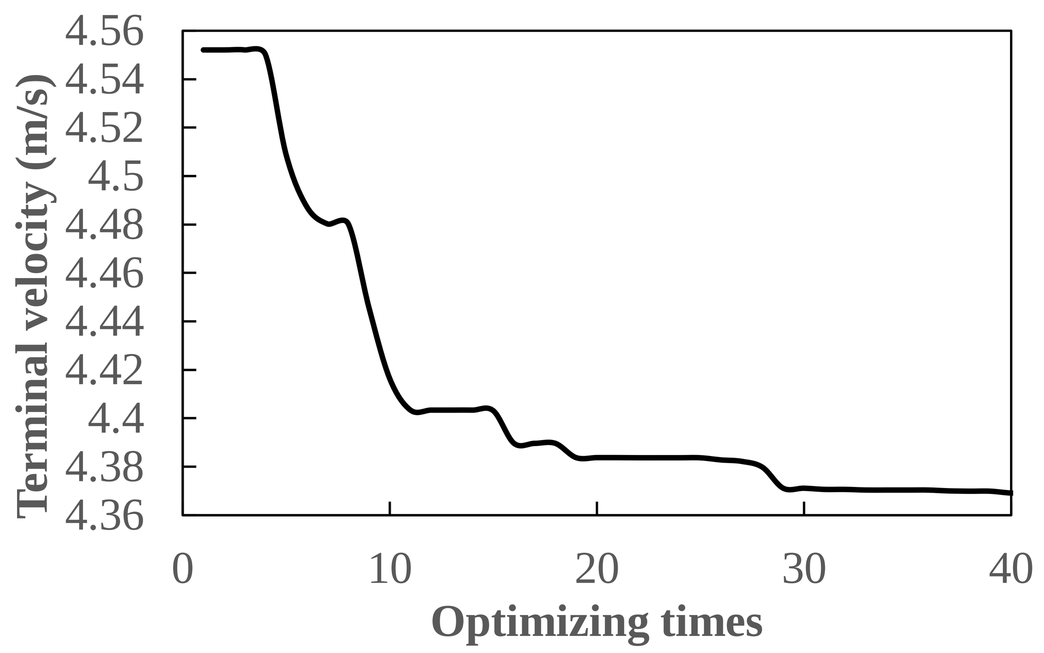


Optimization Model

1) Optimization of Breaking Spring Mechanism

$$\min\ v_{\text{end}}(a,b)$$

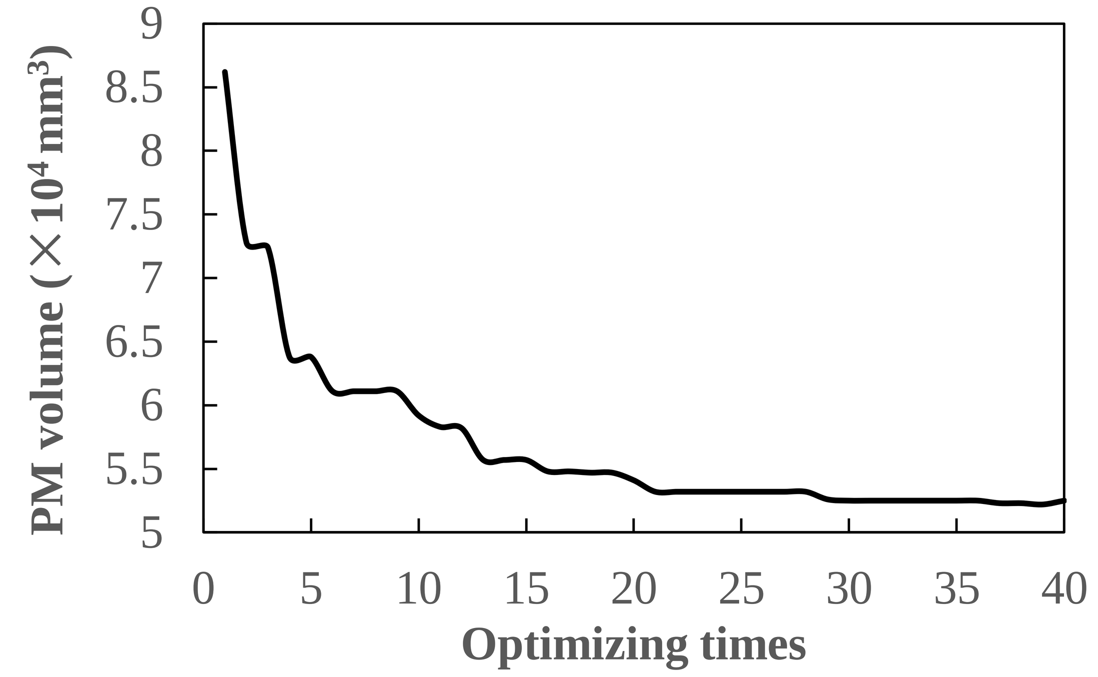
$$\text{s.t.}\ \begin{cases} 3.2\text{m/s} \le v_{\text{av}}(a,b) \le 3.8\text{m/s} \\ a \ge 1200\text{N},\quad b \ge 50000\text{N/m} \end{cases}$$



2) Optimization of PM Holding Mechanism

$$\min V_{\text{PM}}(L_M, h_M, r) = \pi\left(\left(r+L_M\right)^2 - r^2\right)h_M$$

$$\text{s.t.}\ \begin{cases} F_{\text{hold}}(L_M, h_M, r) \ge 17837\text{ N} \\ 2\text{mm} \le L_M \le 20\text{mm},\ 10\text{mm} \le h_M \le 60\text{mm},\ 55\text{mm} \le r \le 200\text{mm} \end{cases}$$



3) Optimization of Closing Driving Mechanism

$$v_{\text{av}}(\boldsymbol{z}) = 0.183 + 0.021z_1 + 0.0103z_2 - 0.0083z_3 - 9.572\times10^{-6}z_1z_2 + 3.895\times10^{-6}z_1z_3 - 1.744\times10^{-6}z_2z_3 - 2.03\times10^{-5}z_1^2 - 2.459\times10^{-5}z_2^2 + 2.622\times10^{-6}z_3^2$$

$$v_{\text{end}}(\boldsymbol{z}) = -16.895 + 0.0844z_1 + 0.2153z_2 - 0.0241z_3 - 5.118\times10^{-4}z_1z_2 + 5.281\times10^{-5}z_1z_3 + 2.616\times10^{-5}z_2z_3 - 6.844\times10^{-5}z_1^2 - 2.112\times10^{-4}z_2^2 - 7.304\times10^{-6}z_3^2$$

$$\min\ v_{\text{end}}(\boldsymbol{z})$$

$$\text{s.t.}\ \begin{cases} 1.7\text{m/s} \le v_{\text{av}}(\boldsymbol{z}) \le 2.3\text{m/s} \\ 350\text{V} \le z_1 \le 400\text{V},\ 60\text{mF} \le z_2 \le 100\text{mF},\ 400 \le z_3 \le 650 \end{cases}$$

Optimization Results

Items	Initial design	Optimized design
Design variables		
Initial pressure of breaking spring (N)	1261	1200
Stiffness of breaking spring (N/m)	100833	166328
Inner radius of PM (mm)	74	75
PM thickness (mm)	8	4
PM height (mm)	26	27
Movable core thickness (mm)	31	29.5
Coil frame height (mm)	62	65
Initial voltage of capacitor (V)	400	350
Capacitance (mF)	90	60
Closing coil turns	735	607
Performances		
PM holding force (N)	14240	17867
PM volume (mm^3)	101940	52474
Average velocity of opening operation (m/s)	2.70	3.2
Terminal velocity of opening operation (m/s)	3.63	4.37
Average velocity of closing operation (m/s)	2.39	2.11
Terminal velocity of closing operation (m/s)	2.82	0.61
Peak current during closing operation (A)	68.1	87.5

Conclusion

The proposed PMA can satisfy the high velocity requirement for opening operation driven by disc spring and auxiliary breaking coil. A multi-step optimization method was adopted and the whole optimization for the PMA was divided into three parts, namely the optimizations of breaking spring mechanism, PM holding mechanism and closing driving mechanism. This method reduces the optimization time. The velocity characteristics of the optimized PMA meet the requirements of a 126kV VCB. The usage amount of the PM and the terminal velocities of opening and closing operations were reduced compared to the initial model, which verifies the validity of the proposed PMA and the effectiveness of the optimization method.

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