Diagrammatized Method of Permanent Magnet Working-point in Polarized System

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Abstract
Polarized magnetic system has widely been used in aeronautical, astronautical, military and civilian domain. Diagrammatized analysis method has advantages of clear physics concept, direct and compendious. The diagrammatized analysis method for work points of the permanent magnet and air magnetic flux for the typical polarized systems are proposed in this paper, which include type differential and bridge magnetic system. The unite calculating expressions are sum up based on the equivalent magnetic voltage model circuit. The diagrammatized analysis method is benefit for understanding the working principle of polarity magnetic system.

Keywords: polarized magnetic system, working point, permanent magnet, diagrammatized method

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1. Introduction
Polarity magnetic system is consisted with two independent magneto motive of polarity magneto motive and working magneto motive. The former one is produced by permanent magnet which is not connected with the state of excited winding current, and the latter is produced by excited winding current. Their resultant electromagnetic force makes the armature of relay move. Polarity magnetic system can response the pole character of input signal, which has performances of low power dissipation, high sensitivity, small volume and light weight [1-7]. The diagrammatized method is used to analyze and calculate the permanent magnet working point of differential and bridge magnetic system. The universal calculate expressions are sum up.

2. Diagrammatized Analysis of Polarity System
Supposing the working point of permanent magnet is at reverting line and ignoring the leakage magnet.

2.1. Differential Type Magnetic System
The configuration and equivalent magnetic circuit of typical differential magnetic system is presented in Figure 1.

Using the node method of magnetic circuit, then

\[ U_A = \frac{IW}{2}G_1 + U_\mu G_0 - \frac{IW}{2}G_2 = \sum G \]  

where, \( G_\sum = G_1 + G_2 + G_0 \).

\( G_1, G_2, G_0 \) is magnetic permeance of gap 1, gap 2 and no-working gap, \( R_\mu \) is equivalent magnetic resistance of permanent magnet. \( IW \) is ampere turns of working winding. \( \Phi_1, \Phi_2, \Phi_\mu \) is flux of gap 1, gap 2 and permanent magnet.

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Supposing $\Phi_0 = U_\mu G_0$ is equivalent short circuit flux, then

$$U_A = \frac{\Phi_1 + \frac{IW}{2} G_1 - \frac{IW}{2} G_2}{G_\Sigma}$$

(2)

According to node equation of the left loop: $\Phi_1 G_1^{-1} + U_A = IW/2$, it can be given

$$\Phi_1 = \frac{G_1}{G_\Sigma} \left[ \frac{IW}{2} (2G_2 + G_0) - \Phi_k \right]$$

(3)

$$\Phi_2 = \frac{G_2}{G_\Sigma} \left[ \frac{IW}{2} (2G_1 + G_0) + \Phi_k \right]$$

(4)

The working magnet flux of permanent magnet is

$$\Phi_\mu = \Phi_2 - \Phi_1 = \frac{IW}{2} \frac{G_0 (G_2 - G_1)}{G_\Sigma} + U_\mu \frac{G_2 + G_1}{G_\Sigma}$$

(5)

Making

$$\Delta G = G_1 - G_2, \Delta G_\delta = \frac{\Delta G}{G_\delta}, G_\delta = G_1 + G_2$$

Then

$$\Phi_\mu = -\frac{IW}{2} \frac{G_0 \cdot \Delta G}{G_\Sigma} + U_\mu \frac{G_0 \cdot G_\delta}{G_\Sigma}$$

(6)

Then making

$$\frac{G_0 \cdot G_\delta}{G_\Sigma} = \frac{G_0 \cdot G_\delta}{G_0 + G_\delta} = (\frac{1}{G_0} + \frac{1}{G_\delta})^{-1} = G$$
From (6) divided by $G$, then

$$U_{\mu} - \frac{IW}{2} \cdot \frac{\Delta G}{G_s} = \Phi_{\mu} G^{-1} \tag{7}$$

According to $U_{\mu} = H_{\mu} I_{\mu}$, $I_{\mu}$ is length of permanent magnet, $\Phi_{\mu} = B_{\mu} S_{\mu}$, $S_{\mu}$ is section area of permanent magnet. then (7) is:

$$H_{\mu} I_{\mu} - \frac{f}{2} \cdot \Delta G = B_{\mu} S_{\mu} G^{-1} \tag{8}$$

Making

$$f = \frac{IW}{l_{\mu}}, \quad \mu_{\perp} = G \frac{l_{\mu}}{S_{\mu}}, \quad \mu_{G} = (\mu_{\perp}^{-1} + \mu_{G0}^{-1})^{-1}$$

Then

$$-H_{\mu} - \frac{f}{2} \cdot \Delta G = \frac{1}{\mu_{G}} \cdot B_{\mu} \tag{9}$$

Connected (9) with reverting curve of permanent magnet, the working point $(B_{\mu}, H_{\mu})$ can be got. And the working point $(B_{\mu}, H_{\mu})$ can be got by diagrammatized method, which is got the point of intersection between reverting line and loading line of permanent magnet.

According to two instances of $(f/2) \cdot \Delta G > 0$ and $(f/2) \cdot \Delta G < 0$, as Figure 2.

When $\frac{f}{2} \Delta G > 0$, the intersection between loading line of permanent magnet and $H$ axis is at the negative half axis. When $\frac{f}{2} \Delta G < 0$, the intersection is at positive half axis.

![Figure 2. Determining the static state working point of permanent magnet with differential type by diagrammatized method](image-url)
2.2. Bridge Magnetic System

The typical bridge magnetic system can be divided into two kinds based on the different location of excited winding. The configuration and equivalent magnetic circuit of the I type is presented in Figure 3.

![Diagram of bridge magnetic system](image)

(a) Polarized magnetic system (b) Equivalent magnetic flux path

Figure 3. Polarized magnetic system and equivalent magnetic flux path of bridge type I

Node equation is given as

\[
\begin{align*}
U_A G_\Sigma - U_B (G_1 + G_2) &= -U_\mu G_0 - \frac{IW}{2} G_1 \\
-U_A + 2U_B &= \frac{IW}{2}
\end{align*}
\]

Then

\[
U_B = \frac{1}{G_\Sigma + G_i} \left[ \frac{IW}{2} (G_2 + G_0) - \Phi_k \right]
\]

Then the working point of magnetic flux is

\[
\Phi_1 = U_\mu G_1 = \frac{G_1}{G_\Sigma + G_0} \left[ \frac{IW}{2} (G_2 + G_0) - U_\mu G_0 \right]
\]

\[
\Phi_2 = (\frac{IW}{2} - U_\mu) G_2 = \frac{G_2}{G_\Sigma + G_0} \left[ \frac{IW}{2} (G_1 + G_0) + U_\mu G_0 \right]
\]

The working point of permanent magnet is

\[
\Phi_\mu = \Phi_2 - \Phi_1 = \frac{1}{G_\Sigma + G_0} \left( -\frac{IW}{2} G_0 \cdot \Delta G + U_\mu G_0 G_\mu \right)
\]
According to \( \frac{G_6 G_\delta}{G_\Sigma + G_0} = \frac{G_6 G_\delta}{G_\delta + 2 G_0} = \left( \frac{2}{G_\delta} + \frac{1}{G_0} \right)^{-1} \) and (14) divided by \( \frac{G_6 G_\delta}{G_\Sigma + G_0} \).

Then

\[
U_\mu - \frac{I W}{2} \cdot \Delta G_\epsilon = \Phi_\mu \left( \frac{2}{G_\delta} + \frac{1}{G_0} \right) \quad (15)
\]

Equation (15) is changed into

\[
-H_\mu - \frac{f}{2} \cdot \Delta G_\epsilon = B_\mu \left( \frac{2}{G_\delta} + \frac{1}{G_0} \right) = \frac{1}{\mu_\Sigma} B_\mu \quad (16)
\]

where \( \mu_\Sigma = \left( \frac{2}{\mu_\delta} + \frac{1}{\mu_{G0}} \right)^{-1} \)

Connected (16) with reverting curve of permanent magnet, the working point \((B_\mu, H_\mu)\) can be got. The diagrammatized method is shown as Figure 4.

![Diagram](image_url)

**Figure 4.** Determining the static state working point of permanent magnet with bridge type I

The configuration and equivalent magnetic circuit of the second bridge type is presented in Figure 5. Node equation is given as

\[
\begin{align*}
U_A &= I W \\
-U_A G_1 + U_B G_\Sigma - U_C G_0 &= U_\mu G_0 \\
-U_A G_2 + U_C G_\Sigma - U_B G_0 &= -U_\mu G_0
\end{align*}
\quad (17)
\]
Then the working point of magnetic flux is

\[
\Phi_1 = \frac{G_1}{G_\Sigma + G_0} \left[ IW (G_2 + G_0) - U_\mu G_0 \right]
\]  

\[
\Phi_2 = \frac{G_2}{G_\Sigma + G_0} \left[ IW (G_1 + G_0) + U_\mu G_0 \right]
\]  

The working point of permanent magnet is

\[
\Phi_\mu = \Phi_2 - \Phi_1 = \frac{1}{G_\Sigma + G_0} \left( -IW \cdot G_0 \cdot \Delta G + U_\mu G_0 G_\delta \right)
\]

\[
= \frac{G_0 G_\delta}{G_\Sigma + G_0} \left( -IW \cdot \Delta G + U_\mu \right)
\]  

Equation (20) divided by \( \frac{G_0 G_\delta}{G_\Sigma + G_0} \), then

\[
U_\mu - IW \cdot \Delta G_\ast = \Phi_\mu \left( \frac{2}{G_\delta} + \frac{1}{G_0} \right)
\]  

Equation (21) can be changed into

\[
-H_\mu - f \cdot \Delta G_\ast = B_\mu \left( \frac{2}{\mu_\delta} + \frac{1}{\mu_{G_0}} \right) = \frac{1}{\mu_\Sigma} B_\mu
\]  

where, \( \mu_\Sigma = \left( \frac{2}{\mu_\delta} + \frac{1}{\mu_{G_0}} \right)^{-1} \)
The diagrammatized method is shown as Figure 6

\[
\begin{align*}
\sum \mu - \mu_H - \mu_B^* \Delta \cdot \mu_G & \quad (a) \quad f \cdot \Delta G_i > 0 \\
\sum \mu - \mu_H - \mu_B^* \Delta \cdot \mu_G & \quad (b) \quad f \cdot \Delta G_i < 0
\end{align*}
\]

Figure 6. Determining the static state working point of permanent magnet with bridge type II

The configuration and equivalent magnetic circuit of the third bridge type is presented in Figure 7.

\[\text{(a) Polarized magnetic system (b) Equivalent magnetic flux path}\]

Figure 7. Polarized magnetic system and equivalent magnetic flux path of bridge type III

Note: where \( G_i \) not exist, make \( G_i = R_{i-1}^{-1} \).

The Equivalent magnetic flux path and calculating expressions are the same as type II, and not been discussed here.
Table 1. Summarization of Parameters

<table>
<thead>
<tr>
<th>Magnetic system</th>
<th>Differential type</th>
<th>Bridge magnetic system Type I</th>
<th>Bridge magnetic system Type II and III</th>
</tr>
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<tbody>
<tr>
<td>Network and referenced direction</td>
<td>1. Referenced direction of $\Phi_1$ and $\Phi_2$ is supposed by $I_W$.</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>2. $\Phi_2 = \Phi_1 + I_{\Phi}$.</td>
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<td></td>
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<td></td>
<td>3. $F_{\Phi}$ and $\Phi_\mu$ are the same direction.</td>
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<td></td>
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<tr>
<td>Basic parameters</td>
<td>$G_{\Phi} = G_1 + G_2$ : $G_1 = (G_0^{-1} + R_{\Phi})^{-1}$</td>
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<tr>
<td></td>
<td>$G_{\Sigma} = G_{\Phi} + G_0$ : $\Delta G = G_1 - G_2$</td>
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<td></td>
<td>$\Delta G_s = \frac{\Delta G}{G_{\Phi}} : f = (I_W)/I_{\Phi}$</td>
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<tr>
<td></td>
<td>$\Phi_k = F_{\Phi}G_1$ ; $\mu_k = G_k \mu S_{\mu}$</td>
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<td></td>
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<tr>
<td>Universal equations</td>
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<td>Gap magnet flux</td>
<td>$\Phi_1 = G_1 \left( F_{\Phi}G_a - \Phi_1 \right)$</td>
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<tr>
<td></td>
<td>$\Phi_2 = G_2 \left( F_{\Phi}G_b + \Phi_k \right)$</td>
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</tr>
<tr>
<td>Permanent magnet flux</td>
<td>$U_{\Phi} - F_{\Phi} \cdot \Delta G_s = \Phi_\mu G_{E}^{-1}$</td>
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<tr>
<td></td>
<td>$- H_{\Phi} - f \cdot \Delta G_s = \frac{1}{\mu\Sigma} \cdot B_{\mu}$</td>
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<td></td>
<td>$\sum G$</td>
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<td>$G_{\Sigma} + G_0$</td>
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<td>Gap Magnet flux</td>
<td>$F_{\Phi}$</td>
<td>$(I_W)/2$</td>
<td>$(I_W)/2$</td>
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<tr>
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<tr>
<td>$\mu\Sigma$</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$G_{E}$</td>
<td>$G_{E} = \left( \frac{1}{G_{\Phi}} + \frac{1}{G_{\Sigma}} \right)^{-1}$</td>
<td>$G_{E} = \left( \frac{2}{\mu_0} \mu - \frac{1}{\mu_{\Sigma}} \right)^{-1}$</td>
<td>$G_{E} = \left( \frac{2}{\mu_0} \mu - \frac{1}{\mu_{\Sigma}} \right)^{-1}$</td>
</tr>
</tbody>
</table>

3. Conclusions

The polarized magnetic system is consisted with two independent magneto motive of polarity magneto motive and working magneto motive. The former one is produced by permanent magnet which is nothing with the state of excited winding current, and the latter is produced by excited winding current. Their resultant electromagnetic force makes the armature of relay move. The diagrammatized method is used to analyze and calculate the gap working point of differential and bridge magnetic system. The universal calculate expressions are sum up.

References


