A study on Improving Performance of an Electromagnetic Clutch though Modified Design

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Abstract – In this paper, we have investigated a high performance electromagnetic clutch for the next generation tank gun. We have studied through reverse engineering based on a structural model of Mayr Power Transmission which occupied most of the world market, and then we made the prototype. We have found some problems through performing the Finite Element Method and the Dynamic Analysis for the prototype. We have met the required specifications through the modified design to solve the problems. Simulation results show that the solutions.

Key Words: Electromagnetic Clutch, Performance Improving Scheme, Modified Design, Finite Element Method (FEM)

I . Introduction

A tank has to avoid collisions with natural objects and structures by disconnecting power sources to be transmitted by a clutch. To achieve this requirement, high torque and high performance electromagnetic clutch (ER clutch) must be needed. The design specifications of the EM clutch presented in this paper are the maximum torque of 50Nm, maximum response time of 40ms, the power consumption of 54W and the input voltage of DC 24V.

These clutches can be mainly classified into a friction clutch, a synchromesh clutch and an air gap clutch. It is most widely used in industrial applications [1]. The magnetic field of ER Clutch is developed nonlinearly and forces due to the field depend on the magnetic path, some previously performed work has been done by the finite element method (FEM) [1]-[8]. The analysis of the electric machinery used the FEM is concerned about the suitable analysis domain, the selection of dimension, the magnetic field and the coupling problem [2].

However, motions of devices have been almost assumed [7], only a translation has been simulated and the friction clutch which is most suitable for the tank has not been adopted [1].

In this paper, the friction clutch was adopted, the field formulation was a magnetostatic field, a 2D-axial model and a weak coupling and the rotation as well as the translation was predicted using the results form FEM. With modified design, this concept removes a phenomenon of magnetic flux bottlenecks and improves a performance of EM clutch.

II . Structure and principle of EM Clutch

The cross-sectional view of the EM Clutch and the names of the principal parts are represented in Fig. 1 and Table 1, prospectively.

![Fig. 1 The cross-sectional view of the EM Clutch](image)

Table 1. Names of the principal parts

<table>
<thead>
<tr>
<th>Number</th>
<th>Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coil</td>
</tr>
<tr>
<td>2</td>
<td>Magnet ASS’Y</td>
</tr>
<tr>
<td>3</td>
<td>Shaft</td>
</tr>
<tr>
<td>4</td>
<td>Plate</td>
</tr>
<tr>
<td>5</td>
<td>Lining</td>
</tr>
<tr>
<td>6</td>
<td>Flange</td>
</tr>
<tr>
<td>7</td>
<td>Spring</td>
</tr>
</tbody>
</table>
The EM Clutch which is a kind of a single disc clutch controls the rotation with the translation. The plate and the flange rotate with the driving shaft and the lining rotates with the driven shaft. When there is no the excitation current and the magnetic field does not exist, the lining is tightly contacted with the plate and the flange because of the spring force and therefore torque is transmitted. At this point, by increasing the excitation current, the torque can be more decreased or cut off, and vice versa.

III. Performance analysis of EM Clutch

3.1 Electromagnetic field modeling

Fig. 2 shows the magnetic path of EM Clutch. It makes the current to flow in which single coil has the turns of coil, and cause magnetomotive force. The current makes the leakage flux $\Phi_l$ and main flux $\Phi_m$ which cause the attractive force in process of magnetic path like Magnet ASS’Y – Shaft – Plate. So, the total flux $\Phi$ of coil is represent from the displacement $x$ of plate and the current $i$ as Eq.(1), it is obtained to use the FEM.

$$\Phi(i, x) = \Phi_m(i, x) + \Phi_l(i, x)$$  (1)

The equivalent circuit of EM Clutch is represented in Fig. 3. Eq.(2) shows that the equivalent circuit is applied to Kirchhoff’s voltage law(KVL).

$$v_{in}(t) = R_c \cdot i(t) + \frac{\partial \lambda}{\partial i} \bigg|_{i=const.} \frac{di}{dt} + \frac{\partial \lambda}{\partial x} \bigg|_{x=const.} \frac{dx}{dt}$$  (2)

Where, $\lambda$ is the linkage flux, $v_{in}$ is the input voltage and $R_c$ is the coil resistance.

3.2 Dynamic Simulation

Fig. 4 represents the maximum torque transferred to the driven shaft. The initial velocity of two axes is made to be same. And the torque is made to increase linearly until the slip occurs. Where the required maximum torques 50[Nm] is not satisfied.

Fig. 5, Fig. 6, Fig. 7 and Fig. 8 showed the current of coils, the attractive force and resultant force of plate, the displacement of plate and torque acting on each shaft. Fig. 9 shows partial derivative of the linkage flux with respect to the currents and Fig. 10 shows partial derivative of the linkage flux with respect to the displacement of the plate. EM clutch attempts to disconnect at 20[ms] and connect at 100[ms].

The area, 20[ms] ~ 28.8[ms] shows that the plate is separated from the lining because the attractive force is bigger than the spring force. The process reconnecting of EM clutch is divided into three areas. The current a rapid decreases in 100[ms] ~ 110[ms] because it is small the variation of the linkage flux.
The current slowly decreases in 110[ms] ~ 165[ms] because it is great the variation of the linkage flux. After 165[ms] shows that the plate is moved because the spring force is bigger than the attractive force. As a result, the required response time, 40[ms] is satisfied the disconnecting time but is not satisfied the reconnecting time.

**Fig. 6** The attractive force and resultant force acting on the plate of the prototype

**Fig. 7** The displacement of the plate of the prototype

**Fig. 8** Torque acting on each shaft of the prototype

**Fig. 9** The partial derivative of the linkage flux with respect to the current of prototype

**Fig. 10** The partial derivative of the linkage flux with respect to the displacement of the prototype

**IV. Improving the performance of EM Clutch**

**4.1 Modified design for the required maximum torque**

The equation of maximum torque specification is verified by Eq.(3) and Eq.(4) [1].

$$T_{max} = n \cdot \left[ \frac{2\mu_s R_{max} (r_1^3 - r_0^3)}{3(r_1^2 - r_0^2)} \right]$$

$$k = \frac{R_{max}}{x_{init}}$$

Where, $\mu_s$ is the coefficient of static friction, $k$ is the spring constant, $r_0$ is the inner radius of the mated surface, $r_1$ is the outer radius of the mated surface, $n$ is the number of mated surface, $x_{init}$ is the initial deformation of the spring, $R_{max}$ is the maximum of the resultant force and $T_{max}$ is the maximum torque of the clutch, respectively. Therefore, Fig. 11 shows to obtain the required maximum torque 50[Nm] by changing the spring.

**Fig. 11** The enhanced maximum torque of the prototype

**4.2 Modified design for the required response velocity**

In this paper, the specification satisfied the response time by decreasing the saturation of the magnetic field. There were
modified design methods that were to change the quality of
the material or the structure and the shape. But, we had
selected the most simply method changing the turns of coil.

Fig. 12 and Fig. 13 show the magnetic path and equivalent
circuit of the modified EM clutch.

From Eq.(5), the resistance of coils satisfied a rated
power/voltage because it is equal to the turns of coils prior to
change. Also, we checked to reduce the magnitude and not to
change direction of the MMF by two coils.

\[ F_{\text{mmf}} = \left( N^+ - N^- \right) \frac{V_{\text{in}}}{2\pi rN/A} \]

where \( N^+ > N^- \)

Where, \( \sigma \) is the conductivity of coils, \( r \) is the average
radius of coils, \( A \) is the cross section of coils, \( F_{\text{mmf}} \) is
MMF(magneto motive force), \( N^+ \) is the turns of coils of the
same direction \( N \), \( N^- \) is the turns of coils of the reverse
direction \( N \), and \( V_{\text{in}} \) is the magnitude of the input voltage,
\( \lambda_{\text{eff}} \) is the composition linkage flux of \( N^+ \) and \( N^- \)
direction.

4.3 Dynamic Simulation of Modified EM Clutch

Fig. 14, Fig. 15, Fig. 16 and Fig. 17 showed the current
response of the improved prototype, the attractive and
resultant force acting on the plate, the displacement of the
plate and torque acting on each shafts. The disconnection
response time satisfied the response velocity although it
increased about 10[ms]. As predicted, about 30[ms], the
connection response time satisfied the response velocity faster
than about 100[ms], prior to improve the performance. In Fig.
14, the reason why the change of the current increases despite
of moving the plate was the moving time was extended
because of reducing the attractive force.
Fig. 18 and Fig. 19 showed the modified partial derivative of the effective linkage flux with respect to the current of the prototype and the displacement. Fig. 18 and Fig. 19 show a remarkable decrease of the linkage flux as compared with Fig. 9 and Fig. 10.

![Graph 1](image1)

Fig. 18 The modified partial derivative of the effective linkage flux with respect to the current of the prototype

![Graph 2](image2)

Fig. 18 The modified partial derivative of the effective linkage flux with respect to the displacement of the prototype

V. Conclusions

In this paper, to localize a high performance electromagnetic clutch for the next generation tank gun, we have investigated a guideline on development of the clutch through reverse engineering based on a structural model of mayr power transmission, headquartered in Germany. We have found some problems by using FEM and Dynamic Model for performance evaluation of the prototype. We have satisfied the required specifications by changing spring and winding.

Acknowledgement

This work is financially supported by the Ministry of Education and Human Resources Development (MOE) and the Ministry of Commerce, Industry and Energy (MOCIE) through the foresting project of the Industrial-Academic Cooperation Centered University.

REFERENCES