Consideration of emf calculation method on an electromagnetic tachometer

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Electromagnetic tachometers are applied to many industry products. The magnetic field analysis is required for these performance evaluation. In this paper, we propose an electromotive force (emf) calculation method for an electromagnetic tachometer system which corrects vector potentials calculated from 2D finite element method in a focused area. The calculated and the measured emf are in agreement with 70%. And tendency of calculated emfs agrees with that of measured emfs. Therefore, the present method has advantages for design and evaluation of an electromagnetic tachometer systems.

Keywords: electromagnetic tachometer, 2D finite element method, emf

1. INTRODUCTION

Electromagnetic tachometers (EMTs) have simple structure, and produce non-contact sensing. They are used in many applications, such as sensors of automobile wheel rotation detection, because of their high reliability(1), (2).

In many cases, they are designed by experience. Optimal design using numerical analysis is necessary to obtain higher performance of EMTs. The 3D or hybrid(3) finite element method (FEM) produces a more accurate evaluation, but it requires a high performance computer, and much time. In this paper, we describe as follows:

(1) The electromotive force (emf) calculation method of an EMT.
(2) Comparison between calculated values and measured values of the emf.

2. PRINCIPLE AND COMPOSITION OF EMT SYSTEM

Figure 1 shows a schematic diagram of an EMT system. The cylindrical-type EMT system is composed of a permanent magnet, a yoke, a case, a detection coil and a toothed wheel. The EMT system is where a narrow air gap separates the EMT placed just a part from the teeth of a wheel. The gap reluctance varies with rotation of the toothed wheel. The emf is derived from the equation (1).

\[ e = -N \frac{d\Phi}{dt} \text{ (V)} \]  

where,
\[ e : \text{emf (V)}, \]
\[ N : \text{turns of detection coil}, \]
\[ \Phi : \text{linkage flux of detection coil (Wb)}, \]
\[ t : \text{time (s)}. \]

Figure 1. A schematic diagram of an EMT system (in mm unit).
3. CALCULATION OF ELECTROMOTIVE FORCE ON EMT

3.1 A magnetic field analysis model

A method of magnetic field analysis of the EMT system is a 2D-FEM. An analysis model is given as an equivalence model in orthogonal system which has cross section areas equal to a cylindrical EMT.

Figure 2 shows an analysis model of the EMT system. In this model, there are 7600 elements and 7800 nodes. The dirichlet condition is given at \( y = 150 \) (mm).

![Figure 2. An analysis model of the EMT system (in mm unit).](image)

3.2 Correction of vector potential

The analysis of the EMT system is a combined problem of an axisymmetric and an orthogonal system. In the analysis of the EMT system using the 2D-FEM, the emfs are evaluated higher than the measured emfs. In this section, the authors propose a method to correct vector potentials from 2D-FEM to evaluate accurately the emfs of the EMT.

Figure 3 and 4 show the flux evaluation in each system, the axisymmetric and the orthogonal system. In figure 3, a flux density \( B_z \) is given from the equation (2).

\[
B_z = \frac{2\pi r A_z}{\pi r^2} \quad (T)
\]

\[
= \frac{2A_z}{r} \quad (T) \quad \cdots \quad (2)
\]

where,

\( B_z \): flux density in \( z \) axis direction (T),

\( A_z \): vector potential in \( z \) axis direction (Wb/m).

In figure 4, a flux density \( B_y \) is given from the equation (3).

\[
B_y = \frac{2 l A_z}{l^2} \quad (T)
\]

\[
= \frac{2A_z}{l} \quad (T) \quad \cdots \quad (3)
\]

where,

\( B_y \): flux density in \( y \) axis direction (T),

\( A_z \): vector potential in \( z \) axis direction (Wb/m).

Each energy of the EMT in the axisymmetric and the orthogonal system should be equal. So the equation (4) is obtained.

\[
B_y^2 = B_z^2 \quad (T) \quad \cdots \quad (4)
\]

Therefore, the relation between the potentials in each system can be shown as following.

\[
A_z = \frac{r}{l} A_z \quad (Wb/m) \quad \cdots \quad (5)
\]

Where the total flux in each system is equal, the following relationship is obtained.

\[
2\pi r A_z = 2l A_z \quad (Wb) \quad \cdots \quad (6)
\]

Therefore, the following relationship is obtained.

\[
l = r \sqrt{\pi} \quad (m) \quad \cdots \quad (7)
\]

From equation (5) and (7), the relationship between the potentials in each system is shown as the equation (8).

\[
A_z = \frac{A_z}{\sqrt{\pi}} \quad (Wb/m) \quad \cdots \quad (8)
\]

Results from the analysis of the cylindrical-type EMT system by the 2D-FEM in the orthogonal system are evaluated by the equation (8).

![Figure 3. Flux evaluation in the axisymmetric system.](image)

![Figure 4. Flux evaluation in the orthogonal system.](image)

3.3 Method of considering recoil permeability

The permanent magnet of the EMT is an Al-Ni-Co alloy magnet. It is necessary to evaluate a recoil permeability for the numerical analysis of the EMT.

Figure 5 shows an evaluation method of a recoil permeability. When the EMT place opposite of the groove of a toothed wheel, the largest reluctance is found. The operation point of the magnet is defined in this situation. In this present analysis, the operation point is defined as the mean value of the flux density of all elements in the magnet that is calculated by using the \( B-H \) curve. The recoil line is drawn on the operation point on the demagnetization curve. This recoil line is defined as a linear \( B-H \) characteristic. The value of the recoil permeability is 3.6 from a specified characteristics of Al-Ni-Co alloy magnet. The operation point varies along the demagnetization curve dependent on the gap length between the yoke and the toothed wheel. Then the recoil permeability is constant. Therefore, the
The coercive force $H_c'$ is given in each gap length.
Table 1 shows the coercive force values for the analysis.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap $g$ (mm)</td>
<td>0.5</td>
</tr>
<tr>
<td>Coercive force</td>
<td></td>
</tr>
<tr>
<td>$H_c'$ (kA/m)</td>
<td>145.9</td>
</tr>
<tr>
<td></td>
<td>144.3</td>
</tr>
<tr>
<td></td>
<td>143.5</td>
</tr>
</tbody>
</table>

Figure 5. An evaluation method of a recoil permeability.

3.4 Calculation method of emf
The linkage flux in the equation (1) is given as the total flux calculated in the inside area of the detection coil, the area of the yoke and the coil bobbin. Variation of the linkage flux is calculated at each point which divides the tooth pitch into 21 sections. The linkage flux of the detection coil varies dependent on the points. The emf is calculated from linkage flux variation in the equation (1).

4. RESULTS OF ANALYSIS
4.1 Calculated analysis
Figure 6 shows distribution of an equi-potential line. The gap length is 1.0 (mm) and the interval of the potential line is 0.3 (mWb). The potential lines are distributed at the center of the magnet. The flux density becomes 1.2 (T) in the upper part of the yoke.

Figure 7 shows characteristics of the emf and the linkage flux. These are the calculated values in conditions where the gap length is 1.0 (mm) and the toothed wheel rotation at 100 (rpm). The linkage flux reaches the maximum value when the EMT positioned upon a teeth, and reaches the minimum value when it positioned upon a groove. The linkage flux and the emf vary like a sine wave. The maximum value of the emf is 66 (mV).

Figure 8 shows characteristics of the emf - gap length at the toothed wheel rotations of 100 (rpm). The calculated values are 30 % higher than the measured values, and the tendency of the calculated values agrees with that of the measured values.

4.2 Discussion
The emf of the EMT system is analyzed by the 2D-FEM. The potentials of the focused area inside the detection coil, are corrected by the proposed method. The emf of the EMT is evaluated from the corrected potentials. The tendency of the calculated values agrees with that of the measured values. This method has advantages in evaluation on a partial area of an EMT.

There are some problems with the overall analysis of the...
EMT system. The 3D analysis is better for accurate evaluation. But this simpler method has advantages in the practical design of EMTs.

5. CONCLUSION

The conclusions of this paper are shown below:
(1) We proposed an evaluation method which focused on a partial area of the EMT system and described the principles of the evaluation method.
(2) The results of emf simulation with the corrected potentials and measurement results are in agreement with 70%. And the tendency of the calculated emf agreed with that of measured.

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REFERENCES


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