Abstract

In recent years, numerous studies have attempted to find and explore the auxiliary brake and the oil pressure type and electrical type are mainly used. However, the model proposed here is to self-excited eddy current brake. The advantage of this is it does not require an external power supply and can be produced to reduce the size than others. This self-eddy current brake consists of RLC circuit so resistance, inductance and capacitance value can be considered a fixed value. But, inductance and resistance value changes depending on the shape, temperature and magnetic alteration. Therefore, in this paper, the focal point is characteristic analysis according to the parameter variations. Also, using this result, this paper explains how to estimate the capacitance.

Keywords: auxiliary brake, self-excited eddy current brake, parameter variations, inductance

1 Introduction

Recently, performance criteria of the secondary braking system that is one of the motor vehicle safety standards have been enhanced to prevent accidents such as downhill pedestrian accident and a large bus. Due to this, the importance of development of secondary brake is on the rise. Existing commercial vehicle has an engine brake which occurs naturally in the structure to assist in the braking force of the foot brake, the exhaust brake to be used by additionally attached to a vehicle, the fluid type retarder and so on.

Self-excited eddy current brake to be studied in this paper is the eddy current brake according to the regenerative braking. In the case of existing electric retarder, this used the battery of the vehicle as a power source. The use of power from the vehicle battery has adverse effects on vehicle fuel economy and lifetime of the battery.

On the other hand self-excited eddy current brake generates a braking torque by using the capacitor to the power supply unit. Therefore, the fuel efficiency and the life of the battery is extended. Also, by using the converter that uses electrical energy generated by the capacitor, it is possible to charge the battery of the vehicle and then it is also possible to obtain a regenerative energy. This self-excited eddy current brake consist of the RLC circuit and it is important to select the appropriate parameters because inductance and resistance value vary according to the shape, temperature, and magnetic changes. So, in this paper, after analysing the value of the parameter by using the basic model, the model is verified through actual simulation by calculating the value of the appropriate capacitor.
2 Principles of the eddy current brake

2.1 Basic theory

For explaining the eddy current brake, a magnet placed between a rotating disk in Figure 1. The electromotive force is induced in accordance with Fleming's right hand rule and then eddy currents are formed. Through this current and the magnetic field, the torque appears to the opposite rotation direction of the disk and this principle has substantially stationary rotating disk.

\[ e = N \frac{d\Phi}{dt} \]  

The maximum torque equation of the eddy current brake is given by

\[ T_m = \frac{K_m}{\pi} \frac{1}{\mu_0} (\pi R^2 L) B_0^2 \]  

\( K_m \) is a numerical factor related to the relative permeability, \( R \) is a radius of the rotor, \( L \) is stack length, and \( B_0 \) is air gap flux density. In other words, the maximum torque is proportional to the rotor volume and the square of the magnetic intensity. Also, the maximum torque is related to the relative permeability, but this is independent of the rotor resistivity.\[1\] Because permeability also affects the inductance value, it is important to use the material with the appropriate value.

2.2 Principles of the self-excited eddy current brake

In principle, the self-excited eddy current brake is similar to the self-excited induction generator to be used in a stand-alone wind power generation system the grid does not exist as shown in Figure 2.

Therefore, it is possible the construction of the d-q axis equivalent circuit with a capacitor in the power supply as shown Figure 3.

\[
\begin{bmatrix}
[i_{dq}] \\
[i_{dc}]
\end{bmatrix}
= \begin{bmatrix}
0 & -V_{cp} \\
-K_{q} & -K_{d}
\end{bmatrix}
\begin{bmatrix}
i_{dq} \\
i_{dc}
\end{bmatrix}
\]

Using the Figure 3, the equivalent circuit equation is as follow

\[
[A] = \begin{bmatrix}
R_c + pL_c + \frac{1}{pC} & 0 & pL_c & 0 \\
pL_c & R_i + pL_i + \frac{1}{pC} & 0 & pL_i \\
-\omega L_m & -\omega L_m & R_c + pL_c & -\omega L_m \\
\omega L_m & \omega L_m & R_i + pL_i & \omega L_i \\
\end{bmatrix}
\]

where \( K_{q} = \omega \lambda_{q0} \) and \( K_{d} = \omega \lambda_{d0} \) are constants, which represent the initial induced voltages along the d-axis and q-axis, respectively.

When the initial start-up, this model is boosting by using the initial fine voltage of the capacitor or fine magnetization of the rotor. When the boosting
is started, the voltage and the current rises, and the braking torque is generated. This boosting proceeds until the core is saturated, and after that converge at the saturation level.[2]

3 Parameter extraction of the self-excited eddy current brake

The shape of the basic model, and a copper coating on the rotor surface to enhance the conductivity of the rotor of the brake is shown in Figure 4.

![Figure 4: Analysis model of the self-excited eddy current brake](image)

Through the equation (3) of the 3-phase self-excited induction generator, to determine whether this model is self-excited or not, this is to solving the characteristic equation that denominator of the \( i_{s\phi} \) becomes zero.

\[
i_{s\phi} = \frac{U}{\Theta} \tag{4}
\]

\[
\Theta = [R_s + pL_s + \frac{1}{j} pC - (p^2 L_s^2 (R_s + pL_s) + pL_s^2 \alpha^2 L_r)]/\Delta
\]

\[
\Delta = (R_s + pL_s)^2 + \alpha^2 L_r^2
\]

It is important to select and extract the parameter, because denominator of the \( i_{s\phi} \) consists of the stator resistance, the rotor resistance, the rotor inductance, the mutual inductance, and capacitance.[2]

In this paper, the parameter is calculated on the basis of one phase because three phases have only the phase difference of 120 degrees and the same size.

3.1 Extraction of the resistance and inductance

In order to determine that is boosting at the start-up, using the method of the lock test and the virtual coil extracts the parameters of the self-excited eddy current brake.

3.1.1 Extraction of the rotor resistance through the lock test

In order to calculate the resistance of the rotor, this is obtained by applying a voltage at winding at a frequency with a 25% of the rated frequency. This voltage is that flows the starting current of the initial start-up. So, it is important to find this value. Through the starting current and the starting voltage, the active power equation of the three-phase is as follow

\[
v_{u,ms}i_{u,ms} + v_{b,ms}i_{b,ms} + v_{c,ms}i_{c,ms} = 3i_{a,ms}^2 R_s + 3i_{a,ms}^2 R_s \tag{5}
\]

When transformed into the expression of this rotor resistance

\[
R_s = \frac{v_{u,ms}i_{u,ms} + v_{b,ms}i_{b,ms} + v_{c,ms}i_{c,ms} - 3i_{a,ms}^2 R_s}{3i_{a,ms}} \tag{6}
\]

Thus, the rotor resistance can be obtained through the lock test as follows.

3.1.2 Extraction of the inductance through the virtual coil

![Figure 5: Extraction of the inductance through the virtual coil](image)

In order to find the inductance value, after placement of the virtual coil at both ends of the one-phase as shown in Figure 5, it is possible to obtain an inductance value by applying a one-phase current only.

By using the flux linkage obtained through the FEM analysis, the stator inductance of the one-phase is obtained as

\[
L_s = \frac{\lambda_{\text{ph, st}}} {i_s} \tag{7}
\]

By using the flux-linkage passing through between the virtual coils, the magnetizing inductance is obtained as

\[
L_m = \frac{\lambda_m} {i_s} \tag{8}
\]

According to the relationship of the equation (7) and (8), the leakage inductance of the stator is obtained as
By using the stator resistance and rotor resistance and the voltage and current used for the lock test, the leakage inductance of the rotor is obtained as

\[ L_{ls} = L_s - L_{m} \]  

(9)

According to the relationship of the equation (8) and (10), the rotor inductance is as follow

\[ L_{r} = L_{in} + L_{l}\phi \]  

(11)

4 Selection of the capacitance and analysis result

4.1 Selection of the capacitance

To determine the capacitance, the denominator of the equation (4) becomes to zero.

\[ 240 \left( \frac{v_{d,ms}}{i_{d,ms}} \right)^2 - (R_s + R_r)^2 \]

\[ \pi \cdot N_{tot,a} \cdot N \]

(10)

According to the relationship of the equation (8) and (10), the rotor inductance is as follow

4.2 Analysis results

After consisting of the external circuit of the model that consists of the resistance, capacitance, the analysis results through the FEM are as follows.

Through the Figure 7, the low-speed range of 1,000 [rpm] ~ 1,500 [rpm] area can be seen that bring a larger capacitance than 1,500 [rpm] ~ 3,000 [rpm]. So, this paper selects the capacitance of 80[uF] to boosting to occur well, because the stator resistance of the one-phase is 0.5[Ω] and operating area is 1,000[rpm] ~ 1,500[rpm].
5 Result

The self-excited eddy current brake is made for supplementing the disadvantages of the eddy current brake and this can contribute to energy savings because it is connected directly to the wheels of the vehicle and then causes the braking torque by the rotational force of the wheel. Also, the self-excited eddy current brake is smaller than the eddy current brake.

The analysis of the parameter variation is important to design the self-excited eddy current brake because the inductances and resistance change depending on the temperature, shape and etc. After that, designer chooses the proper capacitance. If capacitance isn’t proper, the braking torque doesn’t occur.

In this paper, the model is designed to just consider parameter values at start-up. So, this model will be analysed according to parameter variation at the saturation value.

References


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