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Parameter Identification of Eddy Current Braking Sytem for Various Applications

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Abstract—**Eddy Current Brakes offer many advantages over mechanical or frictional brakes. This paper presents various applications of Eddy Current Braking System along with the description of parameters which affect the performance of eddy current brakes.**

Keywords—Eddy Current Brakes;Braking Torque;Braking Distance;Brake-by-Wire

I. INTRODUCTION

Normally automobiles and other vehicles use mechanical friction brakes to provide braking. Conventional friction brakes suffer from various drawbacks like slow response time due to power assistance, wearing of pads and rotors due to friction ,loss of braking torque at high temperature[1]. In this paper various applications of Eddy Current Braking System (ECBS) and parameters corresponding to each application, which affect the performance of ECBS, have been discussed.

II. EDDY CURRENT BRAKING SYSTEM

Whenever a conductor is placed in a time varying magnetic field eddy currents are induced. Relative motion between conductor and magnetic field is required for the production of eddy currents and it can be achieved through either changing the field or moving the conductor in stationary magnetic field.As per Lenz's law generated eddy currents will oppose the cause of their origin i.e. the relative motion between conductor and the magnetic field, so eddy currents will try to stop the motion of the conductor thereby producing the braking action on the conductor. The braking force will be proportional to the amount of relative motion i.e. the speed of the conductor and also on other parameters.ECBS offer many advantages over conventional frictional brakes such as non-contact braking, very fast response time, reduced wear, reduced sensitivity to fading,reduced fuel consumption of power assistance,faster control dynamics,easier integration with anti-lock,traction and dynamic stability controls,electric actuation so no use of fluid,easier individual wheel braking control[1].

III. APPLICATIONS OF EDDY CURRENT BRAKING SYSTEM

A. IN RAILWAYS

Wang and Chiueh [2] described the analysis and use of eddy-current brakes for high speed Railways. Fig.1 shows the use of eddy current brakes in a high-speed train. Eddy Current brakes are used in association with conventional frictional brakes which is known as brake blending or brake assist. In very high speed trains eddy-current brakes are used.

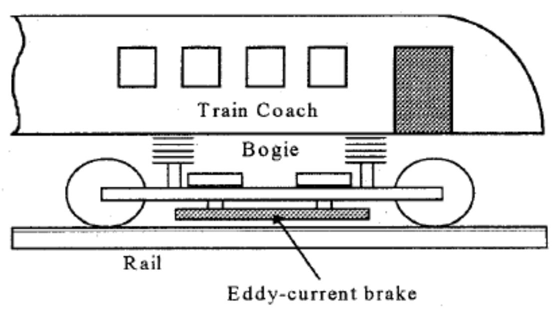

Fig.1. Side –view of the eddy-current brake of a train-bogie

Railways eddy current brakes consist of: - (1) magnetic poles which are dc-excited placed between the wheels and under the train bogie with air-gap above the rail (2) the electrical control systems to control the dc excitation current fed by the power system of the train. When we energize the poles and move them at high speeds above the rail they produce braking forces.

In the ECBS for railways eddy currents are induced in the rails which generate braking force as the vehicle runs [3].It uses the electromagnetic force between the bogie and rails, the ECBS produces the braking force which does not depend on the adhesion between the wheels and rails. One of the problems associated with eddy current brakes is that of rail heating because their principle involves converting the kinetic energy of the vehicles into eddy current loss in the rails.Ryoo et al.[4] discussed the use of ECBS in Korean high speed trains.Fig.2 shows a simple model of eddy-current brake magnet.

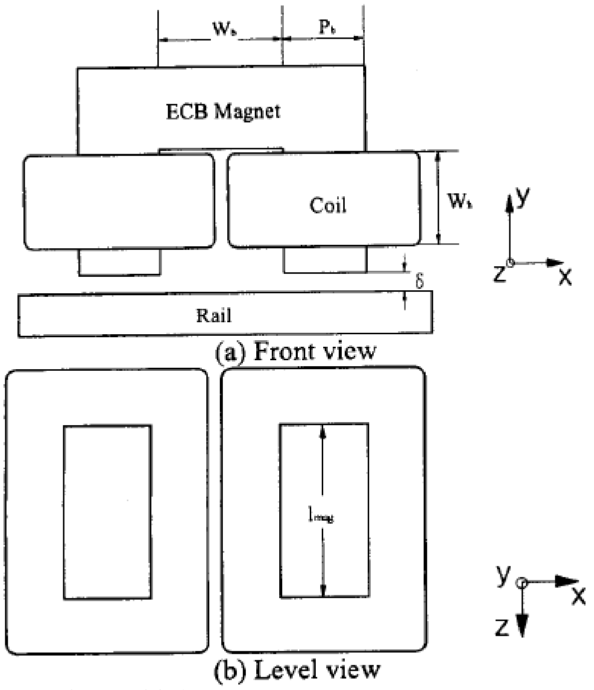

Fig.2. Model of ECBS Magnet

Authors in [5] also discuss the analysis of eddy current brake for high speed trains. This system includes air lift system, brake magnetic system and auxiliary parts of braking. When the train is running at a high speed the braking system results in an eddy current brake through the excitation of the permanent magnet. By varying the current through the exciting coils placed around the permanent magnet, the braking force can be varied. Fujita et al. [6] uses the finite element method to estimate the braking force eddy-current rail brake system. The variation of braking forces with few parameters such a number of poles, pole width and running velocity have been discussed. In the places where pole width is small the magnetic saturation of the pole becomes large resulting in reduced braking force whereas in the areas of greater pole width armature coil cross-section is less the magnetomotive force decreases. In the optimum range of pole width braking force is maximum.

Design and analysis of the axial-flux wound-excitation ECBS have been the subject of [7].Fig. 3 shows an axial-flux wound excitation ECB. Complete parameters of ECB and brake magnet are shown in Table I. The parameters which affect the performance of ECBS for high speed trains are magnetic excitation, pole pitch, pole width, air-gap length, electrical conductivity of rail and rail width.Fig.4 shows one more view of the magnetic system of ECBS for trains.

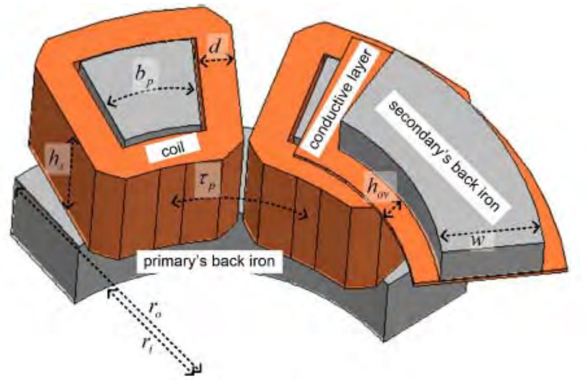

Fig. 3. 3D geometry of axial-flux ECB

TABLE I ECB PARAMETERS

S.No.	Name of Parameter	Symbol
1	Inner radius, Outer Radius	r_i,r_o
2.	Mean Radius	r_m
3.	Air-gap length	g
4.	Conductive layer thickness	l_c
5.	Slot depth	h_s
6.	Mean Pole pitch	τ_p
7.	Mean Pole Width	b_p
8.	Number of Pole pairs	P
9.	Magnetic flux density in the air gap	B_g
10.	Relative Permeability	μ
11.	Electric Conductivity	σ
12.	Magnetomotiveforce	Mmf
13.	Fill factor	k_{fill}
14.	Current Density	J
15.	Cross-sectional area of the conductor	A
16.	Number of turns per coil	N_c
17.	Resistance of coil	R_c
18.	Maximum Power demand for the brake	P_d
19.	Axial length of brake	l_b
20.	Thickness of secondary	t

For a given value of magnetic flux density in the air-gap, the mmf required is given by

$$mmf = \frac{l.B_g}{\mu_o} \qquad (1)$$

In equation (1) l is the sum of g and l_c .The coil cross-section and width are given by-

$$A_{coil} = \frac{mmf}{J.k_{fill}} \qquad (2)$$

$$d = \frac{A_{coil}}{2.h_s} \quad (3)$$

The number of turns per coil is given by

$$N_c = \frac{A_{coil}\, k_{fill}}{a} \quad (4)$$

The maximum power drawn from the supply by the brake is given by

$$P_d = 2p.R_c.\left(\frac{mmf}{N_c{}^2}\right) \quad (5)$$

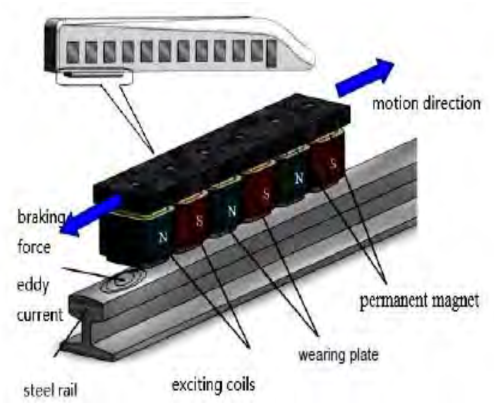

Fig.4. Magnetic system of the eddy current brake system

B. IN AUTOMOTIVE VEHICLES

Eddy current brakes help in vehicle braking specifically in commercial trucks that mostly use mountain road routes [8].ECBS act as brake-assist to existing traditional brakes since the traditional brakes can fail on long downhill mountain passages due to overheating.ECBS is not used in passenger vehicles due to their low torque per unit volume.ECBS may be Electronically controlled (brake-by-wire) at a much faster speed than the traditional frictional hydraulic brakes. The response time is40-50milliseconds for ECBS as compared to300-400millisecond for traditional brakes.Fig.5 shows a schematic diagram of an eddy-current brake with added copper layer on the rotor.

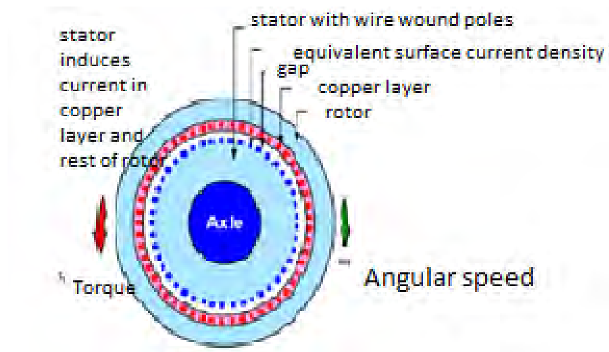

Fig.5. Schematic diagram of an eddy-current brake with added copper layer on the rotor

Peak torque of the ECB can occur outside normal vehicle speed if we don't use copper layer on the rotor. The copper layer results in concentration of current thereby resulting in increased braking torque. According to [8] the performance of ECBS depends on the parameters namely copper layer thickness and excitation current. In braking our objective is to minimize the braking distance i.e. the distance travelled by the vehicle after applying the brakes and before coming to rest. At a particular value of layer thickness peak value of braking torque is achieved. Nowadays antilock braking system(ABS) is used in commercial vehicles[9].Authors in [9] have used fuzzy-logic controller in a hybrid brake system to limit the hydraulic brake pressure at a stationary value when slip ratio reaches 0.2 and current in the ECB is adjusted to keep the optimum slip ratio(0.2).Liu et al.[10] developed a test bed for eddy current braking system and performed the analysis of ECBS.Parameter analysis performed on the test bed concluded that the brake torque decreased significantly as the temperature in the rotor plate increased and reached its maximum value. This adversely affected the performance of the ECBS.Therefore limiting the temperature rise is an important factor for proper performance of the ECBS.

C. AS DAMPERS

Tuned mass damper is a device which which when mounted on structures reduces the vibrations of a flexible structure. But they suffer from certain drawbacks such as they work only in a particular frequency range [11].Eddy current damper or magnetically tuned mass damper is used to suppress vibrations of a cantilever beam. Fig. 6 shows the components of an eddy current damper.

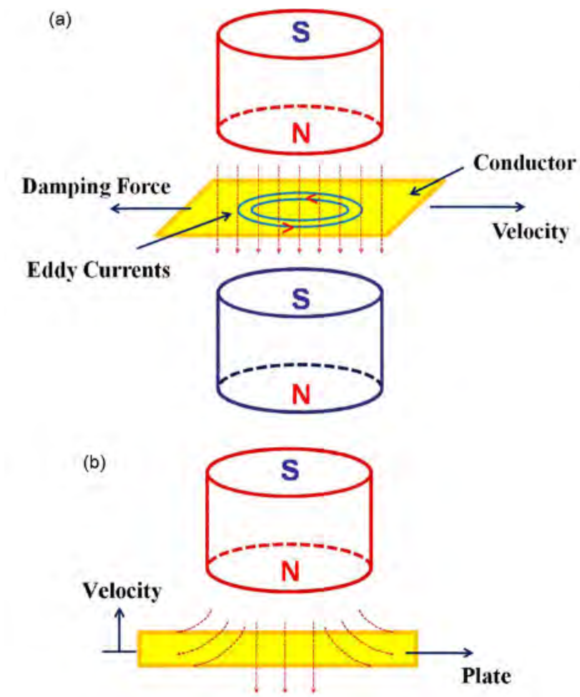

Fig.6. Eddy current damper (a) conductive plate moving perpendicularly to the magnetic pole axis (b) conductive plate oscillating through the magnetic pole axis

The performance of the eddy current damper is affected by the gap between magnet and conducting sheet. Smaller the gap is eddy current damper produces more effective damping.

Performance analysis of eddy current dampers have also been performed by [12].In comparison to dampers based on viscous materials ,electromagnetic dampers based on permanent magnets have less sensitivity to temperature and ageing. Effect of number of magnetic poles and thickness of conductor, permanent magnet on the performance of eddy current dampers has been analyzed.

Eddy current damping of debris found in space which are orbiting around the earth was discussed in [13].The parameters which affect the performance of dampers are thickness of conductor and number of pole pairs. For a given value of conductor thickness and relative speed, number of poles can be varied to achieve maximum torque.

D. AS COUPLERS

Iwanciw and Ashman [14] discussed the application of eddy current coupling in a turbine blade test. The eddy current coupling consists of a ferromagnetic loss drum placed around a field system consisting of alternate poles. There is a small air gap between the drum and pole member. When both members are stationary and the field system is excited, a magnetic field pattern of alternating polarity is created. If we now rotate the field pattern, eddy currents are induced in the drum. Interaction of eddy-current field with the air-gap flux produces a torque which depends on field current and speed. The main parameters which affect the performance of eddy current couplers are air-gap length, relative speed between drum and field poles, magnetic properties of the material of drum. Lesser the air-gap length greater will be the braking torque. Material of drum should have high permeability so that it allows magnetic flux to pass through it easily.

E. IN AIR BEARING SYSTEM

An air bearing system consists of a pressurized thin film of air to support a load. If we move heavy loads on air, it will result in a clean, quiet and safe method which will prevent damaging of floors. Use of eddy current braking in an air bearing system has been discussed in [15].

F. IN AVIATION INDUSTRY

ECBS is used as Energy absorbing system (EAS) in Aircraft Arrester Barrier System (AABS) to stop the high-speed aircrafts which have aborted take-off or emergency landing, from overshooting the runway. AABS are installed near the end of runways .In the conventional rotary hydraulic energy absorbers there is no control on energy absorption during operation of an aircraft emergency arrestment. Also if there is any problem with the conventional EAS the complete system fails.For different types of aircrafts different EAS needed.An eddy current EAS will help in stopping any aircraft of any weight since it produces high and controllable torque[16].

III. CONCLUSION

This paper presented a detailed study on different types Eddy Current Braking System. Various applications of ECBS such as retarders in high speed trains, in automobiles, dampers, couplers and in air bearing system have been studied. Various design parameters on which the performance of ECBS depends have been discussed. It has been observed that some parameters like air gap length, electrical conductivity of conductor, speed of conductor are common in all the applications. Effect of parameters on the performance of ECBS has also been discussed. Main parameters which affect the performance of ECBS are thickness of conductor, air-gap length, electrical conductivity of conductor, magnetic properties of conductor .The value of design parameters should be taken in such a way to achieve optimum braking performance.

References

[1] S.E.Gay and M.Ehsani, "Parametric Analysis of Eddy-Current Brake Performance by 3-D Finite-Element Analysis",IEEE Transactions on Magnetics ,vol. 42,no.2,Feb.2006,pp. 319-328.

[2] P.J.Wang and S.J.Chiueh , "Analysis of eddy-current brakes for high-speed railway" ,IEEE Transactions on Magnetics,vol.34,no.4,July 1998,pp. 1237-1239.

[3] Y.Sakamoto,T.Kashiwagi,T.Sasakawa and N.Fujii, " Linear eddy current brake for railway vehicles using dynamic braking", Proceedings of the IEEE International Conference on Electrical Machines,2008,pp.1-6.

[4] Ryoo et al., "Design and analysis of an eddy-current brake for a high-speed railway train with constant torque control",IEEE conference,2000,pp. 277-281.

[5] J.Ma,B.Zhang,X.Huang,Y.Fang and W.Cao , " Design and analysis of the hybrid excitation rail eddy brake system of high-speed trains",Journal of Zhejiang university applied physics and engineering,2011-12,pp.936-944.

[6] M.Fujita et al. , "3-Dimensional Electromagnetic Analysis and Design of an Eddy-Current Rail Brake System", IEEE Transactions on Magnetics, vol.34, no.5, September 1998,pp.3548-3551.

[7] R.Yazdanpanah and M.Mirsalim, "Axial-flux Wound-excitation eddy-current brakes: Analytical study and Parametric Modeling",IEEE Transactions on Magnetics,vol.50,no.6,June 2014

[8] S.Anwar and R.C.Stevenson, "Torque Characteristics analysis for optimal design of copper-layered eddy current brake system" ,International Journal of Automotive Technology,vol.12,no.4,2011,pp.497-502.

[9] Ren He et al. , " Brake performance analysis of ABS for Eddy Current and Electrohydraulic Hybrid Brake System", Hindawi Publishing Corporation Mathematical Problems in Engineering 2013,pp.1-11.

[10] C.Y.Liu,K.J.Jiang and Y.Zhang, "Design and use of an eddy current retarder in an automobile", International Journal of Automotive Technology,vol.12,no. 4,2011,pp. 611-616.

[11] J.S.Bae et al. , " Vibration suppression of a cantilever beam using magnetically-tuned-mass-damper",Elsevier Journal of sound and vibration,vil.331,2012,pp. 5669-5684.

[12] N.Amati,A.Tonoli,A.Canova,F.Cavalli and M.Padovani, "Dynamic behavior of torsional eddy-current dampers: sensitivity of the design parameters", IEEE Transactions on Magnetics,vol.43,no.7,July 2007,pp. 3266-3277.

[13] N.Praly,M.Hillion,C.Bonnal,J.L.Varin and N.Petit, "Study on the eddy current damping of the spin dynamics of space debris from the Ariane launcher upper stages", Elsevier Acta Astronautica,vol.76,2012,pp.145-153.

[14] P.Iwanciw and K.Ashman, "Application of a high speed, high power eddy current coupling on a turbine test stand", IEE Conference on Electrical Machines and Drives, September 1995, pp. 222-226.

[15] K.K.Tan,S.Huang,C.S.Teo and R.Yang, "Controller design of eddy current braking in an air bearing system" , Elsevier Automatica,vol.48,2012,pp. 2831-2836.

[16] D.K.Chaturvedi and R.K.Sharma, "Modeling and Simulation of force generated in stanchion system of aircraft arrester barrier system", International Journal of Modeling,Measurements and Control,France,vol.64,no.2,1996,pp. 33-51.