Mini Review on Eddy Current Brakes Parameter

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Abstract. The need for braking systems has increased. The widely used braking system is a friction brake. The use of friction brakes has a problem in maintenance intervals and the risk of failure due to heat generation. Research and the development of the braking system have carried out. Eddy Current Brake (ECB) is an alternative braking system. ECB is braking that uses eddy currents as a source of braking force. Many parameters need to consider in implementing the ECB. There have been many studies on the working parameters of the ECB. However, the previous research has researched the effects of parameters by make experiments or mathematical models. This article provides an analysis of the recent research about the ECB performance parameters. From the review of the previous study, it conducted that better performance of ECB is affected by the density of the use of magnetic flux.

1. Introduction
In the hilly and mountainous area, there are a lot of ramp and descent roads that require better braking capability. Better braking performance is also needed for toll roads because the brake will operate at high speeds. This condition is bad for the braking system, especially in friction brakes. The friction-based braking system is a common device to convert kinetic energy into thermal energy through friction between the temperature [1]. A rapid braking process will make the cooling capacity of the brake is not enough to decrease the surface temperature, it becomes the cause of an accident [2].

Research on the development of braking systems has been carried out. The development of friction braking, performance has been carried out in many ways. There is research about the disk and the brake shoes, but the problem was the same in the heat generated [3,4]. There is an alternative braking system using the eddy current, it is called Eddy Current Brake (ECB). ECB is one type of non-conventional brakes, it is commonly used in heavy vehicles like a truck [5]. ECB can be used in high-speed vehicles such as trains [6,7]. In further research, the ECB can be founded on light vehicles application such as motorbikes [8]. ECB is a braking system that uses eddy currents as a source of the braking force. Eddy current is produced by the induction proses of the interaction of the magnetic field with a conductor part [7,9].

One of ECB type that is commonly used is the unipolar design [10]. It is necessary to study several parameters that affect ECB performance. Some of these parameters in on the disk properties [11,12]. Previous research makes a study about the disc thickness ECB braking process. The smaller the thickness of the discs that are used affect the resulting skin effect, and consequently affect changes in braking performance [13,14]. There are various ways to improve ECB performance. The use of
materials and the right air gap will increase the performance of the ECB [15]. There is an influence of heat caused by braking [16]. The effect of the temperature caused by the ECB can cause a shift in the critical speed and the value of the torque. But the previous research didn't study the interaction of the influenced parameters. This article will be focus on a comprehensive analysis of ECB parameters.

2. History of Brake Development for Urban Vehicle

Brake is one of a tool used to slow down or stop the speed of a vehicle. A type of brake that are widely used today are friction brake. Where its use is by clamping the brake disc with brake shoes shown in figure 1. The braking of conventional models results in increased roughness on the surface of the discs and brake shoes.

![Figure 1. Friction brake](image1)

Previous research on the braking system has been carried out. One of the studies is changes the disk material. One of the common materials used is aluminum [17]. In research using aluminum, it is able to provide good heat dissipation [18]. However, the application of braking using aluminum has the disadvantage of being easy to wear, and at high speeds, it is easy to fail [17,18]. Research on braking systems has been carried out with various application models. One alternative braking system used is ECB. One way to conduct this research is to use FEM to analyse the current distribution eddy produced [15]. Besides being influenced by air gaps, ECB performance is affected by the properties of the disk conductor used. Figure 2 shown the eddy current distribution when the braking process.

![Figure 2. Eddy current distribution](image2)
Induction current can be formed when the conductor is in an area with magnetic flux. Eddy currents are also formed from this phenomenon. Another example of the emergence of Eddy currents is the existence of a metal disk rotation which is exposed to a magnetic field that has an air gap in between. Eddy currents will form on the disc and slowly stop the disc spinning. ECB is a braking method that does not require physical contact in the braking process. The ECB works by arranging a magnetic flux source such as a permanent magnet or electromagnet with a disk of conductors connected to a rotating machine. Based on the rotation, the conductor disk will be exposed to the magnetic flux density that can be written on Lenz's law. There are several types of ECB configurations, one of which is ECB with axial configuration. Axial ECB is the most common form of ECB experiment because this configuration is the closest to actual conditions when braking. Another form of ECB braking is ECB braking with a radial configuration. Figure 3 is an axial ECB and the figure 4 is radial ECB.

![Figure 3. Axial-flux ECB][19]  ![Figure 4. Radial-flux ECB][20]

### 3. Brief Algorithm in Computational Instrument
The study was conducted using the FEM method to calculate the eddy current distribution and magnetic field on the disk. Electromagnetic braking torque can be calculated using conventional algorithms. Basically, the FEM process uses governing equations in the form of Maxwell equations. Equation (1) explains Faraday’s law. Then in equation (2), it is Gauss’ law. And equation (3), is Ampere’s law. These equations are the basic equations used in eddy current simulations [21]. Magnetic field (E), flux density (B), current density (J), and time (t).

\[
\nabla \times \vec{E} = - \frac{\partial \vec{B}}{\partial t} \tag{1}
\]

\[
\vec{F} = \vec{j} \times \vec{B} \tag{2}
\]

\[
\vec{T} = \vec{F} \cdot r \tag{3}
\]

The simulation process used has many types of domains, but what is commonly used to conduct electromagnetic simulations is to use the time domain (time-domain method) [22]. The time-domain method was introduced as a method of discretizing time and space that led to a recursive-based time algorithm with the solution of the magnetic field and the electric field from the Maxwell equation determined by the previous step. The time-domain method is used as a method to renew electric fields and magnetic fields in turn. So that there are grid terms, timesteps, and formula updates in this method [23,24]. There is an electric and magnetic field in space and time that must be updated according to the desired number of time steps for each grid used.

### 4. Influence of Air Gap
There is an experiment carried out about the effect of a given air gap. One of the studies conducted was about the tendency of variations in the air gap of 1 mm, 3 mm, and 5 mm [11]. The air gap used
will affect the critical speed caused on the disk surface [25]. Changes in the air gap can also result in changes in the performance of the braking Eddy Current Brake. ECB performance when changing the air gap used is caused by changes in flux density. This is because the farther the distance between the magnetic source and the conductor, the smaller the magnetic effect. In addition, there is an influence of heat generated by braking, but the effect is quite small on the torque produced [16]. The effect of temperature on the ECB can cause a shift in the critical speed and the value of the braking torque. Critical speed is influenced by the skin effect [26], this is caused by the nature of the material's conductivity, the higher the conductivity of the material used, the deeper the magnetic penetration used [9]. Speed changes will affect the magnetic field as shown in figure 5.

![Figure 5. Flux density vs speed [7]](image)

ECB has several types of applications, namely axial and radial ECB in its application when used as a single magnetic source a magnetic field will leak [27,28]. Leaks that occur will result in a decrease in the performance of the ECB used can be overcome by unipolar design shown in figure 6 has a gap on both sides so that the magnetic field will flow without leakage.

![Figure 6. Unipolar ECB [10]](image)

By using a unipolar design, it can be seen that the braking results change along with changes in the air gap. This is consistent with the theory that braking performance is influenced by flux density [29]. ECB performance data when changes in the air gap can be seen in figure 7 based on previous research data [11].
Figure 7. Theoretical vs simulation graph

5. Metallic Based Material in ECB

Research on Eddy Current Brake (ECB) has been carried out so far, one of which is research on the material used. There are many types of materials that can be used as conductors in ECB. The material used can be in the form of aluminium or iron [30], namely as a disk material. Material for motorcycle discs, in general, is iron which is a ferrous material. This type of material is not very suitable for use as a brake disc because the torque produced is relatively low, so it is necessary to replace the material into non-ferrous material. One that has the best torque is the use of ECB using aluminium as the rotor. Figure 8 shown the material changes.

Eddy currents formed from the use of aluminium conductors produce better torque, this is due to the low electrical permeability of aluminium. The use of high electrical permeability will cause the flow of electricity to easily penetrate the disk, so skin effects will form on the surface of the disk [32,33]. In addition to the type of material, disk thickness is also very influential in the ECB braking process. The smaller the thickness of the disc used can affect the skin effect caused and result in changes in braking performance [32]. The design of conductor lamination was shown as in figure 9.
In its application, the use of aluminium has shortcomings at high speeds [34]. This is inversely proportional to the use of Ferro material as a source of magnetic fields used. One solution that can be done is by coating non-ferro material with Ferro material. By coating it will improve braking performance but still has good character, for example, it is with aluminium coated with copper shown in figure 10 [7].

**Figure 9.** ECB with conductor lamination [7]

![Figure 9. ECB with conductor lamination](image)

6. Tendency of Disk Models

Other experiments were also carried out by varying the conductor shape of the braking Eddy Current Brake (ECB). Sooyoung [7], who experimented by adding layers of Al and Cu to a drum-shaped conductor with several thickness variations. Ali [35] experimented by making conductor material into aluminium-iron bimetallic. Then research conducted by Razavi [36] that is making holes in the conductor disk with several variations of the number of holes, and Garbiéc [37] doing research by varying the shape of the conductor disc by making a grating at the edge of the conductor and coating the conductor with copper. Then Sattarov [38], researched by making holes in the conductor in squared form. From their experiments, all variations can give different braking torque results. Previous experiments have proven that changes in shape and material in the ECB conductor affect the braking torque and the spread of magnetic flux. To provide a solution to the problem of magnetic fields, in addition to being able to use disk size changes used shown in figure 11. But also can use a system of adding slotted back iron [39]. The use of this design will help adjust the performance of the ECB with existing needs.

**Figure 10.** Influence of coating type and layer thickness

![Figure 10. Influence of coating type and layer thickness](image)
To provide a solution to the problem of magnetic fields, in addition to being able to use disk size changes used, but also can use a system of adding slotted back iron shown in figure 12 [39]. The use of this design will help adjust the performance of the ECB with existing needs.

The design of the disk used needs to pay attention to the placement of the magnets used. This must be adjusted with consideration of the active region used. Determination of the right active region will provide good braking performance because it will provide the right arm force with the right size and provide optimal magnetic field density. The region in ECB shown in figure 13 and the influence of the slot in the figure 14.
The use of the slotted design will also provide different performance, this is due to the existence of the slotted will provide a large enough magnetic field concentration in the given slot. This will result in improved braking performance. By looking at previous studies there is a comparative analysis of brakes with slotted and plain shows that the ECB torque generated by the slotted disk design is greater than plain [38].

![Figure 14. Influence in slotted ECB [38]](image)

7. Conclusion
ECB has been used for various types of applications. Much research has been conducted to improve performance and improve energy efficiency used. In addition, many studies on improvements in ECB design were conducted. Magnetic flux is the most influential parameter in ECB performance. By defining the best parameters in the ECB will get a good braking performance. The improvement of the brake performance will affected by the changes in the parameters. By looking at the results of existing research it is known that the need for ECB development in the future is for characterization of the ECB. The ECB is strongly influenced by disk properties. Better performance of the ECB can be made by improving the magnetic flux.

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