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Investigation On Conventional Braking With High Speed Performance Electromagnetic Braking System

Dr.K.G.Saravanan[1], S.Pradeep[2]
[1]*Associate Professor, Department of Mechanical Engineering, Sona College of Technology, Salem, Tamil Nadu*
[1]*kgsmechanical@gmail.com*
[2]*M.E. – Engineering Design, Department of Mechanical Engineering*
Sona College of Technology, Salem, Tamil Nadu

Abstract

The braking is the action of making a moving vehicle to stop or slow down by applying the brake. According to our day to day life there are many advance technology in the braking system are used to be developed in the mechanical field. the electromagnetic braking concept are one of the latest developing technology focused by many companies to overcome the problem faced in the conventional braking system and they believe that the electromagnetic braking system reduce the braking distance compare to the conventional braking system. In the conventional braking process the movement of vehicle slowdown or stop by using frictional force. The friction between two surface pressures together to convert kinetic energy to heat energy by this energy conversion the vehicle movement is used to be stop. In the electromagnetic braking system we used magnetic field to stop the movement of the vehicle, hence the friction is very less compare to the conventional braking system. The electromagnet are made by the current carrying coil which is winded over the iron core. When the current is used to pass over the coil it produce magnetic field by this concept the electromagnetic braking is used to be function. The speed of the braking is high because of the movement of the electron, as per the research the electron speed is less than one percent of light speed. Due to this property the electromagnetic braking are used to produce high braking torque in short interval of time. The most common problem in the conventional braking system is high generation of heat and produce high wear and tear .in the electromagnetic braking system the braking is done by frictionless concept, hence there is no heat generation and high wear and tear production. In this project we combined the electromagnetic braking and conventional braking to make a result of high performance braking system. the project explain that the conventional braking system are work for particular speed limit of the vehicle, when the vehicle reached above the speed limit the electromagnetic braking system is used to combine with conventional braking system to stop the movement of the vehicle and to reduce the braking distance. We use speed sensor and control system to monitor the movement of the vehicle and the braking system. Moreover we used the electromagnetic braking concept as high speed performance braking not as the emergency braking.

Keywords: *frictionless braking, electrical braking, electromagnetic braking, current coil brakin*

1 Introduction:

Electromagnet is the one of the type of magnet, which the magnetic field is produced when the current is passed through it. The electromagnet is first inverted by William sturgeon who was an English physicist. The electromagnet is powerful then the permanent magnet, the magnetic field are used to be produced based on the flow of current to the circuit. There are various type of braking system in the automobile field such as disc brake, drum brake, hydraulic brake, air brake etc. this types of conventional braking provides highest range of friction which produce wear and tear, in this type of braking system the heat generation is also high. Compare to the conventional braking system the heat generated in the electromagnetic braking system is low, in this braking system the brake are used to be applied by the

electrical current passed to the insulated copper wire which produce the magnetic field, this magnetic field are used to stop the movement of the wheel rotation which produce less friction while Appling the brake. Actually this electromagnetic braking system is not used in the vehicles because of some issues. The electromagnetic braking are used to be work by the current which is passed to the winded wire, the battery in the vehicle are used to give the current to that electromagnetic brake. If we want more effective brake without affect the other performance of the vehicle we can used to placed separate battery of this braking system also, but the problem is we cannot predict the braking situation of the vehicle, when we apply the braking in the short interval of time for several times the battery are used to be dry quickly. Due to this major issues the electromagnetic braking are not used as regular braking system in the automobile field. it can be tough to place a large battery setup for the braking system, so we used to make this braking system as high speed performance braking. The procedure of this high speed performing braking system explain that the brake are used to be activated above the particular range of speed of the vehicle. Consider a car moving below the fixed range of speed, the brake is used to be applied to the fixed range only the conventional braking are used to be stop the car. The brake is applied over the fixed range of speed the combination of conventional braking system and electromagnetic braking system are used to stop the vehicle. in this project we used to design and test the performance of the electromagnetic braking system at lab condition, for this testing process we frame a experiment set up and examine the results of electromagnetic braking system. The experimental set up are used to frame by the induction motor, rim wheel ,brake drum ,electromagnetic plate, speed sensor, battery, millimeter. In this project we used to collect the result under the lab condition so we use the induction motor to run the experimental set up. The speed sensor is used to calculate the speed of the wheel rotation, when the brake drum is used to apply the brake to the wheel. The electromagnetic disc are used to generate the magnetic field during the braking process, the millimeter are used to measure the passing current and voltage value of the electromagnetic disc. The battery is used to give the current to the electromagnetic brake disc to produce the magnetic field. The experiment is perform under the varies speed of range and the result are used to be collected. According to the value of the result we conclude the performance of the electromagnetic braking system.

2 Problem Identification

According to the study of literature review, there are varies types of problem are mention against the convention braking system. This problem is the key for the new advance development of the braking system. Some of the list of problem are used to be mention here.

1) The conventional braking system working by converting the kinetic energy to the heat energy to stop the vehicle when the brake are used to be applied. In this process of braking the heat generation is high, due to the friction between the brake shoe and brake pad. In this braking system the brake fade are used to be arise.
2) The conventional braking system produces high braking distance after applying of brake. To overcome this problem the effective braking design are needed, to reduce the braking distance for this system.
3) In the conventional braking system, when the sudden brake are used to be applied to the vehicle the slipping are produce.
4) The conventional braking system need high braking maintance, due to heat which is produce by the wear and tear during the braking process.
5) The problem arises in the conventional braking affect the performance of the vehicle during the braking process.

3 Major Components

3.1 Drum brake:

Figure 1: Drum brake

The brake is used to stop the vehicle by Appling friction force on the braking drum. When the brake is applied the kinetic energy converted to heat energy by this process the wheel rotational is used to be arrested by the frictional force. The brake design is varies according to the vehicle, but the principle of braking is common. During the braking the heat is produce between the brake shoe and drum by the frictional force, when they are in contact and it dissipated by the air. The brake drum is used to be manufacture by the cast iron, in some special cases it is used to be manufacture by the steel. The cast iron brake drum are preferred, because we use both conventional braking and electromagnetic braking system to stop the vehicle. The cast iron material are used to performed in both electromagnetic braking and conventional braking system, the cast iron have the quality of attracted towards the magnetic field when the electromagnetic braking system are used to be applied to it.

3.2 Electromagnetic disc:

Figure 2: Electromagnetic disc

The electromagnet disc is made up of iron core and current caring copper wire. The core are used to be mounted in the drum, this drum is in fixed condition. When the current is applied to the copper wire, the magnetic field is used to be created which is used to arrest the movement of the wheel rotation. The iron core is used to increase the magnetic field which is created by the current pass to the wire. In the electromagnet the magnetic field are used to be increase by increasing the current passed to the copper wire, number of rotation of copper wire and decrease in length of the iron core. The electromagnet is to be produce according to the need of the user, based on the required magnetic field. the electromagnetic concept explain that the current caring wire produce the magnetic field in the perpendicular direction of current flow, based on this principle the electromagnet are used to be worked. The electromagnet does not have any required systematic structure, it can be design based on the user.

3.3 Rim wheel:

Figure 3: Rim wheel

The wheel is the one of the rotational part of the vehicle, which transfer the vehicle from one place to another place. At initial stages of vehicle manufacturing, the steel wheel are used. the steel wheel use to have high strengthen properties, but it expose some problems like produce more braking heat. In latest technology the wheel rims are used to be manufacturing by magnesium and aluminum alloy. The size and design of the rim are varies according to the capacity of the vehicle.

3.4 Induction motor:

Figure 4; Induction motor

In this experimental process the wheel is used to be rotated by the help of the induction motor, we use single phase induction motor. In the induction motor the torque is produce by the reaction between the magnetic field and the current induced in the coil. The single phase induction motor is used for smaller load purpose and the alternative current is used as the power supplied to the induction motor. In the induction motor the number of turns in the coil is high, hence it can used for high speed rotation purpose. In latest electronic vehicle the induction motor are used, the motor can be varies according to the load of the vehicle. The main advantage of induction motor is, which produce the efficiency of 97%.the induction motor rotor are in two types either in wound type or in squirrel cage type.

3.5 Multi meter:

Figure 5: Multi meter

Multi meter is the electronic measuring instrument which is used to measure the flow of current, voltage and resistance through the circuit. This multi meter is used to measure the particular range of value, it also design to measure both alternative current and direct current through the circuit. There are two types of multi meter which is used to measure the reading, one is analog multi meter and another is digital multi meter. The analog multi meter shows the reading by using the pointer, in some cases the small deflection in the analog multi meter changes the accuracy of the valve. The digital multi meter the reading are used to be display in led display, the digital multi meter is more accurate than the analog multi meter. The measuring of current voltage and resistance value are display in decimal value, so the accuracy range is high. The multi meter is works by the number of electron passed through it at certain interval of time. It measure maximum current range 10amps and maximum voltage range of 600v.

3.6 Battery:

Figure 6: Battery

The battery is the power storing device, which is consist of one or more electrochemical cell. The chemicals in the battery release the energy which is convert directly as electrical energy. The voltage released by the battery is depend on the electrochemical cell used in the battery. The positive terminal of the battery is known as cathode and the negative terminal of the battery are known as anode. The battery store the energy according to the size and the electrochemical cell used in the battery. The primary battery is use once and it cannot be recharge again and the secondary battery is discharge and charge again at many number of times. The compound used in the battery are varies according to the application, for example the lead acid battery are used in the vehicle and the lithium ion batteries are used in the laptop charger, smart phones.

3.7 Speed sensor:

Figure 7: Speed sensor

The speed sensor is one of the type of the tachometer. In deduct the speed of the wheel rotation in the vehicle. The speed sensor are initial work with the mechanical linkage and later it is worked by the toothed ring and setup. The speed sensor is not used only for calculate the rotation of the wheel in the vehicle, in the latest technology the speed sensor is used for the braking purpose. The anti-locking braking system are work by the help of speed sensor. The speed sensor sense the speed of the vehicle and pass the information to the abs braking control system, the braking system applies the force to the wheel according to the speed of wheel rotation. The wheel is connected to the tooth ring, when the wheel is used to be rotate the tooth produce the pulse signal to the braking control system. According to the pulse the brake are used to be applied to the wheel. If the pulse signal is high the speed of the wheel rotation is high, for that high braking torque are required to stop the wheel. If the pulse signal is low the speed of the wheel rotation is low, for that low braking torque is enough to stop the wheel. In our experiment we use the speed sensor to sense the speed of the wheel. The different types of speed sensors are Speed sensors based on the Hall Effect, Speed sensors with mechanical tendon and Inductive speed sensors.

4 Construction

Figure 8: Construction

In the experimental setup we use conventional braking system and electronic braking system so we used cast iron drum for braking process. The selection of brake disc material is done, according to the experiment we used to be performing against the braking system. The one side of the wheel is connected to the induction motor by the chain drive and other side of the wheel are used to attach with electromagnetic plate.

We made the electromagnet at the circular structural position, this structural position refers that the magnet used to be produce the magnetic field over all the circular structure. The electromagnetic disc contain the iron core which is fixed permanently over the iron drum, the iron core are placed in the circular structure. Each iron core are used to be winded with the copper coil, all the starting point of each copper coil winding are connected to the cathode and all the ending point of each copper coil winding are connected to the cathode of the battery. The charges flow to the copper coil winding at the same time it produce high amount of the magnetic field in the electromagnetic disc, if the current flow in the copper coil winding is high then the magnetic field produce in the electromagnetic disc is also high. In other ways also we can produce the high amount of magnetic field to the electromagnetic disc, which is done by winding more number of turn in the iron core of the disc. The one more way to increase the magnetic field is to decrease the iron core size. This is the three possible ways to increase the magnetic field. In this experiment we used to fix the iron core and to increase the number of turn in the winding coil, the result of the magnetic field which is produce in the experiment concluded the values of performances. The induction motor is attached to the other side of the wheel by chain drive.

The induction motor used to rotate the wheel. The speed can be varies using the speed controller, this speed controller used to reduce or to increase the speed of the motor and make a speed difference in wheel rotation. This speed is used to be decrease or increase by varies the current supplied, which is done by speed control switch to the induction motor. The speed of the motor is based on the load applied to the induction motor, when the load is high the speed of the motor is low, when the load is low the speed of the motor is high. The induction motor is directly attached to the wheel, which is use to rotate the wheel. The wheel rotation can be monitor by the speed sensor, when the wheel reached the required rpm the motor use to be power off. After the power off the brake are used to be applied to the wheel and the reading are used to be taken. This process used to be continues for to take some set of reading. The induction motor reach high speed at short interval of time, for this experimental purpose we use this motor.

The multi meter is used to calculate the flow of current from the battery to the electromagnetic disc plate. According to the flow of current in the circuit, the electromagnetic disc is used to be produce magnetic field to stop the rotation of the wheel. When the high amount of current passed at short interval of time then the magnetic field produced in the electromagnetic disc is high, when the low amount of current passed at short interval of time then the magnetic field produce in the electromagnetic disc is low. The magnetic field are used to stop the wheel movement and the braking time are used to be noted to apply in the calculation. The current and voltage flow in the electromagnetic brake is required to find the braking torque. In our experiment we used to pass high value of the current to the circuit to get high magnetic field, we use battery to produce the magnetic field. The multi meter measure the each and every second of the battery current, which is flow to the electromagnetic disc plate. The flow of current is important in the every part of the calculation purpose and to get the result values

We use battery to produce magnetic field to the electromagnetic disc plate. The positive terminal of the battery is use to connected with the starting of the winding wire in electromagnetic disc plate and the negative terminal of the battery are used to be connected with the end of the winding wire in electromagnetic disc plate. When the current is passed the winding wire produce the magnetic field over the electromagnetic disc plate. This magnetic field is use to stop the movement of the wheel. The braking time are used to be calculated by the time taken for the wheel to stop from the running speed to the required speed .this calculation are used to result the force expressed in the electromagnetic plate when the current is passed to it.

The speed sensor is placed in the bottom of the electromagnetic braking disc.the sensor produce the pulse to calculate the speed of rotation. The pulse signal is low the speed of the wheel rotation is low, for that low braking torque is enough to stop the wheel. The wheel is used to be rotated by the help of the

induction motor, hence the speed of the wheel are not use to calculate. The speed sensor are used to deduct the speed of the wheel rotate by the induction motor, This reading are used to taken for the calculation purpose. By this calculation we can use to get the result of the braking torque, magnetic flux calculation of the experiment.

4.1 Working principle:

The electrical current has the ability to produce the magnetic field in a plane which is perpendicular to the direction of current flow. The strength of the field produce is proportional to the increase in current flow, increase in number of turns and decrease in size of solenoid. The electromagnetic principle is used to frame the electromagnetic brake disc for our experiment. The experimental setup is run by the induction motor, which the electrical energy are converted into mechanical work. When the current passes to the motor, the electromagnetic coil are used to rotate the motor. According to the load applied to the motor, the coil thickness and the size are used to be varies. For the continues load purposes direct current motor are used and for the limited load purposes the alternative current motor are used.

The speed sensor is placed below the electromagnetic disc. The speed sensor used to measure the speed of the wheel rotation. When the wheel is rotated, the speed sensor generates the pulse signal. The speed of the wheel are calculated by the pulse signal. The pulse signal generate only the wheel are used to be rotate. This pulse signal is used to be monitor by the control unit. The control unit used to pass the current to the electromagnetic disc brake.

The multi meter is measure the flow of current and voltage to the electromagnetic disc brake. When the current is passed to the multi meter, it measure the amount of electrons passed to the required amount of time. Based on this concept the multi meter is used to measure the flow of current and voltages to the electromagnetic disc plate. The magnetic field is used to be produce, based on the flow of current and voltage to the electromagnetic plate. The control system is used to monitor and send feedback to the user. It monitors the speed of the wheel movement and current passed to the induction motor.

The battery is used to send the power to the electromagnetic disc plate. The power passed to the battery is used to be monitor by the multi meter. The direction of the magnetic field flows on the direction of the current passes through the copper wire. Hence the initial turns in the coil are connected to the cathode and the final turns are connected to the anode. When the battery connected to the coil, the charges are used to flow on the coil by the chemical reaction in the battery. The battery used to convert the chemical reaction to the electrical power, due to this process the power are used to be convert to the electromagnetic disc plate.

The drum brake is also used in this experiment. The brake system is work by the frictional force generated by the brake shoe and the brake drum. Due to this frictional force the heat is occur and it disappear in the air. The kinetic energy is converted into heat energy, which stops the movement of the vehicle.

4.2 Design and calculation:

Data:

1) Mass (m)– 11 kg
2) Braking time(t)- 2.2sec
3) Diameter of wheel (d)- 0.250m
4) rotational speed of wheel(N) - 130 rpm
5) Radius of disc(Rd) – 0.8 m

6) Wheel ratio/ diameter of disc(R) – 1.563
7) Coefficient of friction (μ)– 0.25
8) Effective disc radius(Re) – 0.06m
9) Current through coil (I)– 8 amp-hr
10) Length of solenoid(L) – 0.050 m
11) Electrical disc conductivity of iron(P)- 59.6 x 106 s/m
12) Electromagnet radius (r)- 0.015m
13) Battery voltage(V) – 12 v
14) Battery current(I) - 8 amp-hr
15) Specific heat capacity of disc(C) – 465 J/Kg ^{o}c
16) Thermal conductivity of disc(k) – 54 watt/m ^{o}c
17) Disc volume(v) – 3.6×10^{-5}
18) Density of disc(p) – 7850 kg/m^3
19) Permeability of air(μo) - $4\pi \times 10^{-7}$
20) Permeability of steel(μs) - 2000

Braking force:

The braking force are calculated by the Newton's second law

$V = \pi \times d \times N / 60$
$= (\pi \times 0.250 \times 130)/ 60$
$= 1.70$ m/sec
$A = (v-u)/t$
$= (1.70-0)/2.2$
$= 0.77$ m/sec^2

$F = m \times A$

$= 11 \times 0.64$

$= 8.5$ N

$T= (F \times 0.5d)/R$

$= (8.5 \times 0.125)/1.563$

$= 0.679$ Nm

Clamp force:

$C= T/ (\mu \times Re \times n)$

$= 0.679/(0.25x0.06x1)$

$=44.6$ N

Brake power:

$K.E = ½ (mv^2)$
$=1/2 (11) (1.70)^2$

$=15.90^{J}$

For clear explanation the braking force calculated for constant mass of 1600kg of a car with variable speed and braking distance are tabulated:

Example 1:
Mass=1600 kg
Velocity= 25m/sec (90KM/H)
Braking distance=50m

K.E = ½ (mv^2)
$=1/2\ (1600)\ (25)^2$
$=5 \times 10^5$ J

W= F x S
F =W/S
$=5 \times 10^5/50$
=10000 N OR 10 K

Example 2:
Mass=1600 kg
Velocity= 11.2m/sec (40KM/H)
Braking distance=30m
K.E = ½ (mv^2)
$=1/2\ (1600)\ (11.2)^2$
=100352 J
W= F x S
F =W/S
=100352/30
=3293 N OR 3.3 KN

Example 1:
Mass=1600 kg
Velocity= 33.33m/sec (120KM/H)
Braking distance=20m
K.E = ½ (mv^2)
$=1/2\ (1600)\ (33.33)^2$
=888712 J
W= F x S
F =W/S
=5888712/20
=44444 N OR 4.4 KN

Table 1: The braking force tabulation is calculated for constant mass of 1600kg for a car as per the above method:

	1 INCH	**1 FEET**	**1 METER**	**5 METER**	**10 METER**	**20 METER**	**30 METER**	**40 METER**	**50 METER**
10KM/H	242914 N	20243N	6170N	1234N	617N	309N	206N	155N	124N

20KM/H	823000N	81004N	24690N	4938N	2469N	1235N	823N	618N	494N
30KM/H	1853334N	182415N	55600N	11120N	5556N	2778N	1852N	1389N	1112N
40KM/H	329333N	324147N	98800N	19760N	9877N	4939N	3293N	2470N	1976N
50KM/H	6102363N	508531N	155000N	31000N	15431N	7716N	5144N	3857N	3087N
60KM/H	8779528N	731628N	223000N	44600N	22221N	11111N	7407N	5556N	4445N
70KM/H	11929134N	994095N	303000N	60600N	30246N	15123N	10082N	7562N	6050N
80KM/H	15590552N	1299213N	396000N	79200N	39506N	19753N	13169N	9877N	7902N
90KM/H	19685040N	1640420N	500000N	100000N	50000N	25000N	16667N	12500N	10000N
100KM/H	24330708N	2027560N	618000N	123600N	61730N	30865N	20580N	15433N	12346N
110 KM/H	29409449N	2450788N	747000N	149400N	74689N	37345N	24897N	18673N	14938N
120 KM/H	35000000N	2916667N	889000N	177800N	88888N	44444N	29630N	22222N	17778N
130 KM/H	41338583N	3444882N	1050000N	210000N	104374N	52188N	34792N	26095N	20876N
140 KM/H	47637796N	3969817N	1210000N	242000N	120996N	60499N	40333N	30249N	24199N
150 KM/H	55118111N	4593176N	1400000N	280000N	138912N	69456N	46303N	34728N	27783N

Rotational energy:

$P=E/t$

$=15.90/2.2$

$=7.23$ watt

Brake heating

Fade stop temperature rise:

$\Delta t =(P \times t)/(\rho \times c \times v)$

$= (7.23x2.2)/ (7850x465x (3.6x10^{-5}))$

$= 16/ 131.41$

$=0.121\ ^{o}c$

Magnetic flux density:

$B = (\mu s \times \mu o \times n \times I) / L$

$= (2000 \times (4 \pi \times 10^{-7}) \times 250 \times 8) / (0.050 \times 5)$

$= 5.03 / 0.25$

$= 20.12 \text{ wb/m}^2$

Magnetic field strength:

$H = (N \times I) / L$

$= (250 \times 8) / .25$

$= 8000 \text{ A/m}$

4.3 Justification:

1) As per the tabulation we can able to chart a force, braking distance and braking force. A car of mass 1600kg moves at the speed of 40km/h. the car need to stop at 30 meters, it required 3293N braking force.

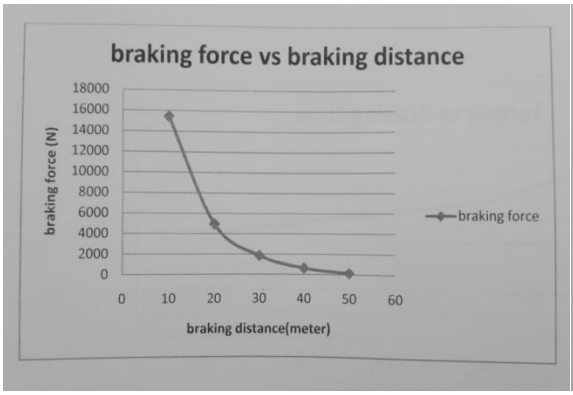
2) A car of mass 1600kg, it has the braking force of 823N and braking distance of 30 meter. Then the car movie at the speed of 20km/h

3) A car of mass 1600kg, it moves on the speed of 70km/h and the braking force of 7562N. Then the braking distance of the car is 40 meter.

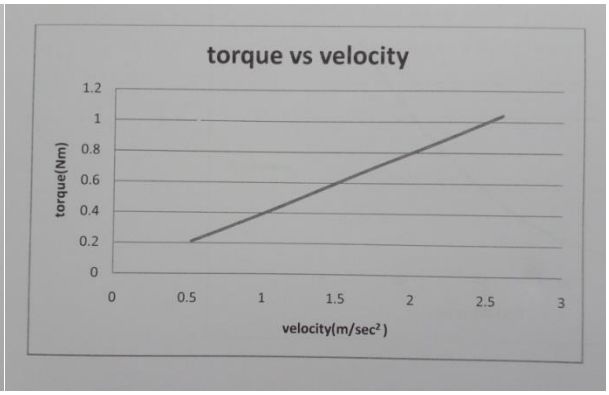
4) A car of mass 1600kg, it has the braking distance of 5 meter and braking force of 31000N.then the car speed of the car moves at 50km/h.

5) A car of mass 1600kg, it moves at the speed of 90 km/h and braking distance of 50meter.then the braking force of the car is 10000N.

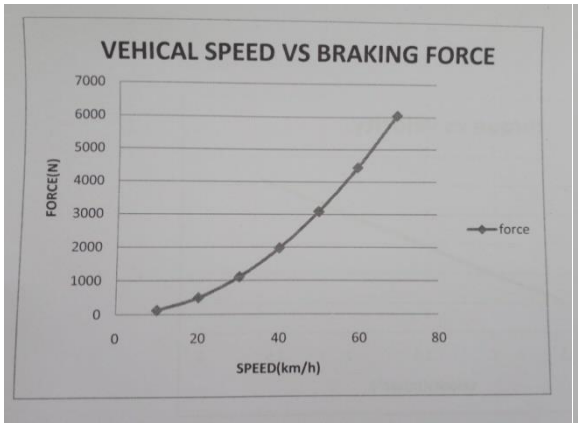
4.4 Graphs:



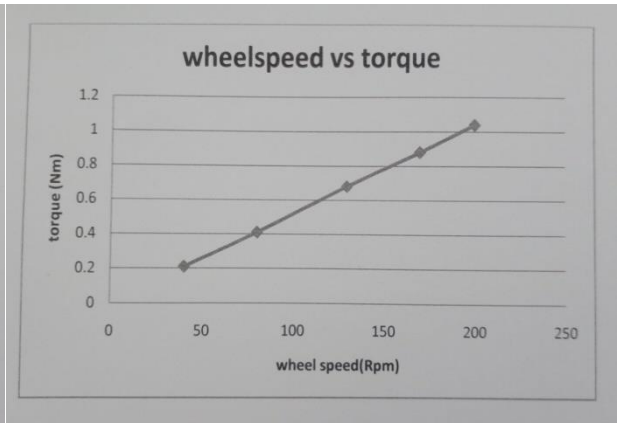
Graph: 1



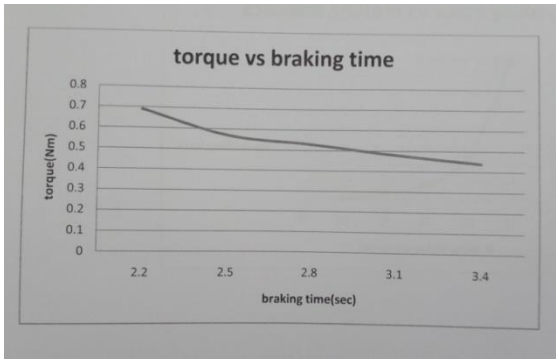
Graph: 2



Graph: 3



Graph: 4



Graph: 5

Graph: 1

The graph is plotted between the braking force and the braking distance. This graph mentions that the braking force required is high, when the brake is applied in shorter distance.

Graph: 2

This graph is plotted between the torque and velocity. When the velocity is high the torque required to produce for the braking is also high.

Graph: 3

This graph is plotted between the wheel speed and braking force. As per the graph that the wheel speed increases the braking force required to stop the wheel is high.

Graph: 4

This graph is plotted between the vehicle speed and torque. As per the graph that the vehicle speed increases the braking force required to stop the wheel is high.

Graph: 5

This graph is plotted between the torque and braking time. As per the graph that the vehicle braking time increases the torque required to stop the wheel is decrease.

5 Conclusion

The electromagnetic braking system is more effective compare to the other braking system. The conventional braking system produce high slipping and this braking system possess high braking distance, when the sudden brake is used to be applied to it. The electromagnetic system are design to reduce the braking distance and to reduce the slipping factor when the sudden brake is applied. The electromagnet braking is complete working under the electrical control so the process used to be done quickly. The reaction time of the braking system is very less so we can produce effective braking and reduce the braking distance of vehicle after Appling the brake. The electromagnetic braking system produce required amount of magnetic field to stop the moving part. It produce the high magnetic field energy by the current passed to the circuit, hence the braking efficiency is high. As our experiment result that the electromagnetic braking system reduce the braking time compare to the conventional braking system. This experiment is conducted in the lab condition for the small setup. According to our experiment we study that the sudden power drop occurs when the electromagnet is highly charged. This is happen because we used more number of turns to produce high magnetic field and the current required is also high.

We passed the electrical current through the battery to the electromagnetic plate, we note that the battery are used to be dry quickly. In this experiment we used more number of turned coil to produce the magnetic field, hence the battery dry is occur. As we get the required braking power to stop the vehicle, we need to control the power drop during the braking system. This experiment produce the positive values based on the result, we make this project as high speed performing braking system. The high speed performing braking work only the vehicle react it required speed level, so the energy required to produce magnetic field is less. To achieve high performance electromagnetic braking process we need more power generation, we plan to develop our experiment to the next level in future.

4.5 Nomenclature

t - Braking time

I - current

N - Wheel speed rotation in rpm

C - Specific heat capacity of disc

μ - Coefficient of friction

K - Thermal conductivity of disc

Re - Effective disc radius

P - Density of disc

P - Electrical disc conductivity

μo - Permeability of air

V - Voltage

μs - Permeability of steel

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