Disk Brake Performance Test Bench Using Equivalent Vehicle Inertia

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ABSTRACT

Our project is centred on a test bench that is used to emulate the performance of disk brakes of different automotive vehicles. The project has 2 parts, hardware part and software part. The hardware part is fabricated in MRC and it has been tested before it can be used for large scale production.

To check the performance of disk brakes, companies have to make prototype first to see whether it will work as it is supposed to be, or not?

This entire process is extremely costly, tedious and time taking. It hurts a companies' financial reserves real bad.

Our test bench is the answer to this problem. It can accurately test a brake's performance so that industries and companies no longer have to wait for the prototype. What took millions of rupees to accomplish, will now take thousands only. What took months to achieve, can now be achieved in a matter of hours.

PREFACE

The disc brake performance test bench provides an easy to use and convenient way to evaluate the conditions of any disc brake using the actual vehicle dynamics. The test bench simulates the conditions of an actual vehicle using equivalent inertia of the vehicle and proves it's results by comparing it with a user friendly software that displays the results corresponding to the vehicle parameters given by the user which makes the process further convenient and sustainable.

ACKNOWLEDGMENTS

All praises and thanks to Allah, the Most Beneficial and the Most Merciful, for bestowing on us all the blessings in our lives. Praise be to Allah, for the blessing of being in Ummah of His last and beloved Prophet Hazrat Muhammad (SAW). Praise be to Allah for giving us strength and guidance and lending us His invisible hand throughout our lives. Alhamdulillah! The compilation and completion of this thesis would not have been possible without the all-out help and support of the very kind people around us, to only some of whom it is possible to give particular mention here. Dr. Riaz Mufti , Dr. Mian Ashfaq, Dr. Amir Mubasher, Dr. Sami ur Rehman Shah, and Col. Naveed.

We would also like to thank the whole crew of MRC especially Sir Faisal for being so cooperative and helpful. We must record our thankfulness to our fellow UG students of ME-05, for creating a collaborative, comfortable, congenial environment to work wholeheartedly. It was a wonderful experience working and studying with all of you.

The prayers, wishes, cooperation and perpetual assistance of our most beloved family members deserve a special mention. Our parents, siblings and close friends whom we consider to be our family too; comprehending this humongous task would not have been possible without your eternal support and best wishes.

ORIGINALITY REPORT

We certify that this thesis report titled as “Disk *Brake Performance Test Bench”* is our own work. The work has not been presented elsewhere for assessment, yet. The material that has been used from other sources it has been properly acknowledged / referred.

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ABBREVIATIONS

- **MRC** Manufacturing resource center
- **mm** millimeter
- **Kg** kilogram
- **J** Joule
- **K** Kelvin
- **m** Meter
- **N** Newton
- **Rpm** Rounds per meter
- **Hp** Horsepower

NOMENCLATURE

M:	Mass
V:	Velocity
ω:	Angular Velocity
r:	radius
I:	Inertia
J:	Moment of inertia
G:	Gear Ratio
T:	Torque
F:	Force
E:	Total Kinetic Energy
m_e:	Equivalent mass
δ:	Rotational Inertia Factor
J_{ew}:	Equivalent Rotational Inertia
F_w:	Effective Force
F_t:	Total Traction Force
F_g:	Slope Resistance
F_a:	Aerodynamic Resistive Force
F_r:	Rolling Friction Force
f_r:	Rolling Resistance Coefficient
C_d:	Drag Coefficient
ρ:	Density of Air

r_e:	Effective Radius
D:	Disc Useable Outside Diameter
d:	Disc Useable Inside Diameter
C:	Brake Clamp Load (N)
T:	Brake Torque (Nm)
U_f:	Coefficient of Friction
n:	Number of Friction Face

CHAPTER 1

INTRODUCTION

Background

Our project is centred on a test bench that is used to emulate the performance of disc brakes of different automotive vehicles. The project has 2 parts, hardware part and software part. The hardware part is based on emulation of moment of inertia of an automotive vehicle at specific gear ratio, rpm and velocity. We emulated the moment of inertia of 6^{th} Generation Honda Civic at 4^{th} gear, 900 rpm and 100 km per hour velocity with scaling factor of 1/16.

The other part comprises of a user interface that takes input in the form of vehicle parameters such as car specification, braking force or distance, gear ratio and initial velocity and displays the performance parameters of the disc brake in readable form and visual graphs.

Aims and Objectives

The main objective of the project is to evaluate the performance of a particular disc brake through comparison between results obtained from experimentation on the prototype (hardware) and calculated results given by software.

We are to develop a software that takes input from user in terms of car specification, braking force or distance, gear ratio and initial velocity. We will get the output in terms of Braking force (if braking distance is used as input), braking distance (if braking force is used as input) and equivalent parameters for test bench.

We are to back the results of software with a prototype. The prototype will simulate different real world conditions. Initial rpm will be given to the equivalent vehicle inertia and then certain braking force will be applied to it. The results will show the braking distance. Braking distance of vehicle obtained from software and prototype will be compared for validity.

Application

The test bench will provide a user friendly easy to use and time saving way of evaluating the performance of different disc brakes at specific drive conditions.

As a result the old conservative ways of testing a brake on an actual vehicle prototype can be avoided by using the test bench to evaluate the key performance parameters affecting the braking phenomenon using the test bench which will provide equally accurate results in a much more effective and friendly manner.

ORGANIZATION OF THE REPORT

In chapter one the project is introduced covering the areas such as background information, aims & objectives and the applications of the project.

In chapter two the review of literature is presented. It summarizes the existing knowledge in the area of the project while referring to significant publications (books, research papers) in the area of the research work. This chapter explains the theoretical aspects of the project in light of the already done research in the respective field of science.

The chapter three of the report comprises of the methodology which was followed from the first step till the last, covering all the actual work done on the project and elaborating parts such design, fabrication etc

The next chapter shows the final outcomes of the projects and it’s comparison with the previously determined results that can be drawn from the already present research in the respective field.

The final gives the comprehensive conclusion of the project while putting a light on the future prospects our project has to offer and what work can be done in the future in this field to make it more effective in the future.

CHAPTER 2

LITERATURE REVIEW

This part involved the study of the already work that has been done by the engineering community around the globe to get the basic insight into the project. It also enabled us to get a head start since this is a widely researched field and the work of our fellow engineers helped us a lot. The theoretical concept building was also an important aim of the literature reviewing part of the project.

Emulating the inertia of a vehicle using a large flywheel

The most crucial part of the project was to accurately calculate the rotational inertia of flywheel that can be used to simulate the vehicle conditions using the linear inertia of the vehicle. To serve the purpose two methods could have been used i.e.

- Kinetic Energy Method
- Vehicle and Motor Dynamic Equations

Kinetic Energy Method:

Since we know the total kinetic energy of a body is the sum of its rotational and translational kinetic energy.

$$E=\frac{1}{2}mv^2 + Jw_w^2$$

Where m is the true static mass of the moving body which in our case is a vehicle, v is the linear velocity of the tires, J is the inertia of all the rotating components of the vehicle calculated at the tires and omega is the angular velocity again calculated at the wheels. [4]

Now the above equation can be replaced by substituting the non-rotating energy of a body whose equivalent mass me is such that the total kinetic energy remains same at the same speed.[4]

$$\frac{1}{2}m_e v^2 = \frac{1}{2}mv^2 + Jw_w^2$$

Where me is the equivalent mass here and can be defined as a mass increase due to the angular moments of the rotating parts of the vehicle. Now after manipulation of the above equation we get

$$m_e = m + j(\frac{1}{r_d})^2$$

Now to calculate the value of me one must first determine the rotational inertia of J of all the rotating parts of the moving assembly. This requires the knowledge of weight and complete dimensions of the rotating parts. An easy way given in the literature to calculate this equivalent mass me requires determining a rotational inertia factor, as show below

$$m_e = \delta \times m$$

Where delta here is the rotational inertia factor or mass factor given by

$$\delta = 1 + \frac{I_w}{Mr_d^2} + \frac{i_o^2 i_g^2 I_p}{Mr_d^2}$$

This calculation further requires the knowledge of dimensions of the rotating parts but it can be reduced to a standard empirical equation, whose estimated value for a passenger car is given by[4]

$$\delta = 1 + \delta_1 + \delta_1 i_o^2 i_g^2$$

And after substituting the empirical values we get

$$\delta = 1 + 0.04 + 0.0025G^2$$

Here G is the gear ratio. (Vehicle Fundamentals) (Vehicle Fundamentals)

After calculating the equivalent mass of the vehicle we can easily calculate Je the equivalent rotational inertia of the vehicle by taking into account the fact that kinetic energy is due to the virtue of motion of a mass and remains same whether the mass is moving in straight line or in a circle. Therefore we can equate the kinetic energy due to linear motion and due to the rotational motion.[4]

$$J_{ew} = m_e \frac{v^2}{\omega_{w^2}}$$

Where Jew the equivalent rotational inertia calculated at the wheel and can be given as:[4]

$$J_{ew} = m_e \frac{v^2}{\omega_{w^2}}$$

After substituting the value of linear velocity from the relation of linear and rotational velocity we get [4]

$$J_{ew} = m_e r_{d^2}$$

Also the value of equivalent rotational inertia at the engine side can be calculated by using the overall transmission ratio G:[4]

$$J_{ew} = \frac{m_e r_{d^2}}{G^2}$$

Using Vehicle and Motor Dynamic Equations

The governing equation for the movement of a vehicle can be written as:

$$F_w = m_e \frac{dv}{dt}$$

Here F_w is the effective force acting in the vehicle's direction and me is the equivalent mass as calculated in the previous section. The resistive forces have not been taken into account in the above equation.[4]

Also the equation for the object connected to the vehicle's traction motor and spinning with the same angular velocity, having the rotational inertia J_{em}, is given as:[4]

$$T_m = J_{em} \times (\frac{d\omega_m}{dt})$$

Now the equation relating the change in angular velocity of a traction motor with the change in its linear velocity is given by:

$$(\frac{d\omega_m}{dt})=(\frac{dv}{dt}) \times \frac{1}{r_d} \times G$$

Manipulating the above equations we get the result[4]

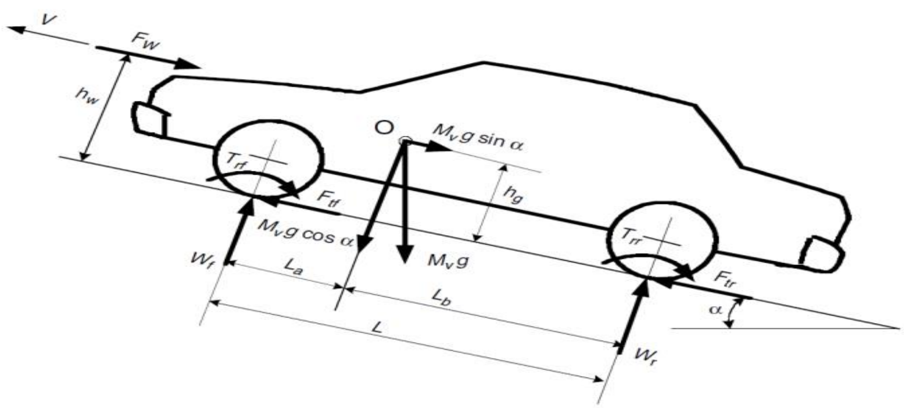
$$J_{ew} = \frac{m_e r_{d^2}}{G^2}$$

Which same as in the previous case for the equivalent rotational inertia at the motor side.

Simulating the conditions for a moving vehicle

The first and the most important part in simulating the actual conditions for a moving vehicle is the mathematical modeling of the vehicle involving all the necessary forces and parameters affecting the vehicles motion. For this purpose we found different approaches to find the suitable equivalences for our test bench that emulates a dynamic vehicle.

Vehicle Equivalence



[7]

Figure 1: Vehicle Dynamics

The equation that describes the motion of a moving vehicle, derived from the equation of dynamic equilibrium, is given as:

$$m\ddot{x} = F_t - F_g - F_a - F_r$$

Here ‘’a’’ is the acceleration of the vehicle in the linear direction and the forces F_t, F_g, F_a and F_r represent the total traction force, slope resistance, aerodynamic resistive force and rolling friction force respectively. The values of whom are given below:[7]

Rolling Resistance

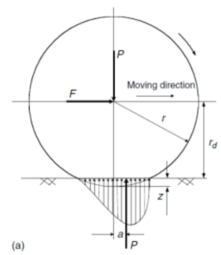


Figure 2: Rolling Resistance [7]

$$F_r = mgf_r cos \propto$$

Fr-rolling resistance coefficient

Table 1: Rolling Resistance [7]

Conditions	Rolling resistance
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02

Aerodynamic Drag

A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is referred to as aerodynamic drag. It mainly results from two components: shape drag and skin friction.[7]

Shape drag: The forward motion of the vehicle pushes the air in front of it.

$$F_w = \frac{1}{2}\rho ACV^2$$

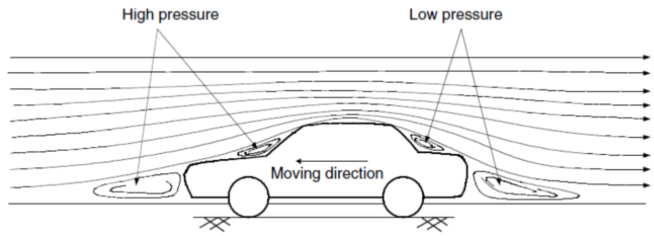
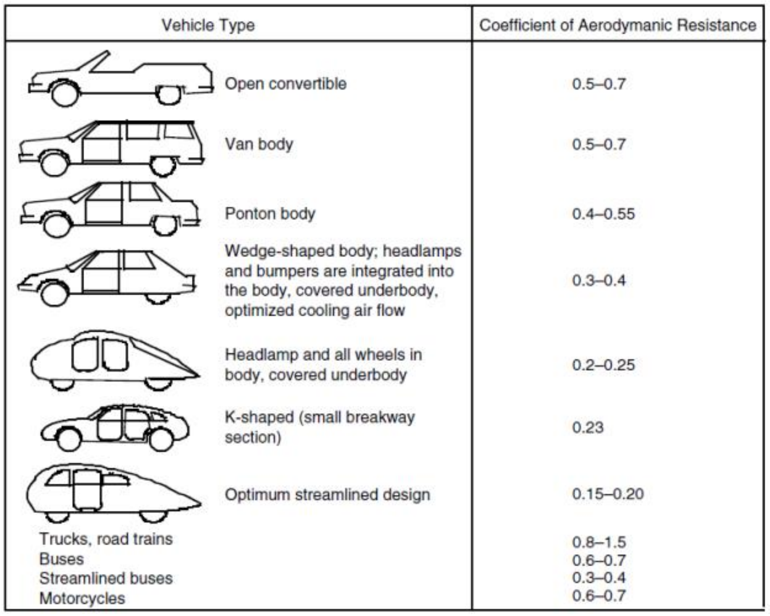


Figure 3: Vehicle Drag [7]

Skin friction: Air close to the skin of the vehicle moves almost at the speed of the vehicle while air far from the vehicle remains still. In between, air molecules move at a wide range of speeds. The difference in speed between two air molecules produces a friction that results in the second component of aerodynamic drag. Aerodynamic drag is a function of vehicle speed V, vehicle frontal area A_f, shape of the vehicle, and air density ρ. Aerodynamic drag is expressed as [7]

Where C_D is the aerodynamic drag coefficient that characterizes the shape of the vehicle and $V\omega$ is the component of wind speed on the vehicle's moving direction, which has a positive sign when this component is opposite to the vehicle speed and a negative sign when it is in the same direction as vehicle speed.

The aerodynamic drag coefficients for a few types of vehicle body shapes are shown in Figure.[7]



Vehicle Type	Coefficient of Aerodymanic Resistance
Open convertible	0.5–0.7
Van body	0.5–0.7
Ponton body	0.4–0.55
Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4
Headlamp and all wheels in body, covered underbody	0.2–0.25
K-shaped (small breakway section)	0.23
Optimum streamlined design	0.15–0.20
Trucks, road trains	0.8–1.5
Buses	0.6–0.7
Streamlined buses	0.3–0.4
Motorcycles	0.6–0.7

Figure 4: Drag Coefficients [7]

Weight Force[i]

$$F_g = mgsen\alpha$$

Therefore the combined equation for a vehicle is:

$$m\ddot{x} = F_t - mgsen \propto - \frac{C\rho V^2 A}{2} f_r mgcos\alpha$$

Braking system

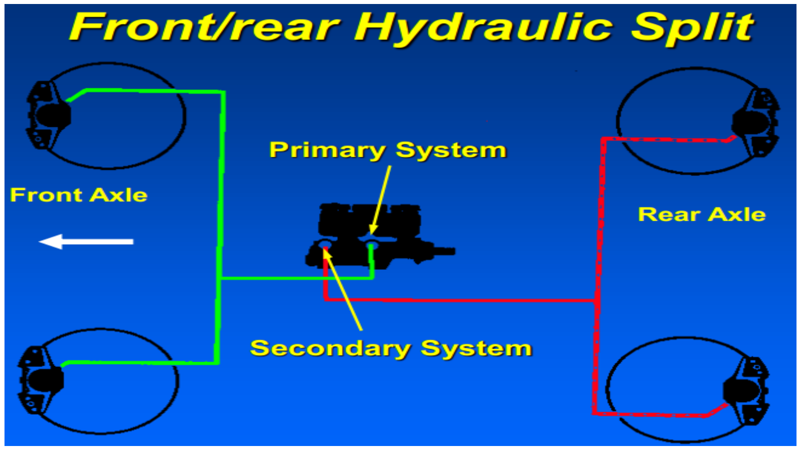


Figure 5: Brake System [2]

Components

Master cylinder

Master cylinder is just a piston in a cylinder

Front disk brake

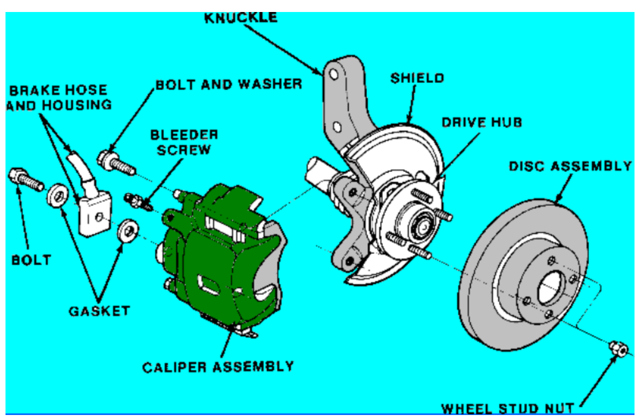


Figure 6: Front Disc Brake [2]

There are many different designs but all contain the following basic parts:

• Caliper body

• Bleed Screw

• Pistons

• Piston seals

• Dust boots

• Pads

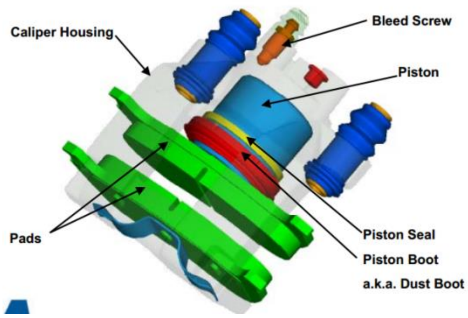


Figure 7: Disc Brake [2]

Brake system calculations

Disc Effective Radius

The effective radius (torque radius) of a brake disc is the center of the brake pads by area.

For dry discs it is assumed to be: [9]

$$r_e = \frac{D+d}{4}$$

Where:

r_e=effective radius (m)

D= disc useable outside diameter (m)

d=disc useable inside diameter (m)

Clamp Load [9]

$$C=\frac{T}{n.U_f.r_e}$$

Where:

C = brake clamp load (N)

T = brake Torque (Nm)

r_e = effective radius (m)

U_f = coefficient of friction

n = number of friction face

The clamping load is assumed to act on all friction surfaces equally. For dry disc brakes it doesn't matter whether the brake is of the sliding type or opposed piston. Newton's Third Law state every force has an equal and opposite reaction and a reaction force from a sliding caliper is the same as an opposed piston one.[9]

CHAPTER 3

METHODOLOGY

The design methodology of the test bench has been focused on the reproduction of the vehicle dynamics close to the real application. Two approaches of analysis have been taken into account in this methodology:

a) The simulation of vehicle by the implementation of a mathematical model using software

b) An experimental way using a test bench implementation. The vehicle model developed is close to the real application with a great flexibility to modify the parameters of the vehicle. However, in spite of having a test bench close to the real application, the parameters to be changed are limited by the natural configuration of the test bench. However, flexibility of variation is possible in the moment of inertia (J). Once the analysis of the dynamic movement of the Vehicle has been defined, the vehicle test bench can be designed from the mathematical representation.

$$m\frac{dv}{dt}=F_t - F_g - F_a - F_r$$

Equation

$$F_t - Traction\ force$$

$$F_g - Force\ due\ to\ weight$$

$$F_a - Force\ due\ to\ aerodynamics$$

$$F_r - Rolling\ Friction$$

Based on the equation above the dynamic of movement of the vehicle can be emulated by the proposed test bench, which is composed of an inertial flywheel and a motor. Effect of drag force & rolling friction is ignored because of is negligible effect on results. The flywheel can emulate the dynamic behavior of the through the moment of inertia (*J*), which represents the equivalence of the mass of the vehicle.

$$J\frac{dw}{dt} = \tau_t$$

In order to achieve the emulation of the vehicle by the proposed test bench, some considerations have to be taken into account:

The moment of inertia and the torques have to be affected by a scaling factor (*Rt*) in order to reproduce the dynamic of a particular vehicle of interest. This can be defined by the rates of the motor power, the vehicle of interest and the motor of the test bench.

Functionality, Design & components

Software

This software is developed in Matlab to assist user in finding

1. Brake distances
2. Braking time
3. Brake force
4. Temperature of disk

Upon inputting following parameters

1. Vehicle parameters

2. Prototype parameters
3. Disk brake parameters

Allowing following selections

Input Brake force on vehicle and calculate the results or input brake distance and calculate the results

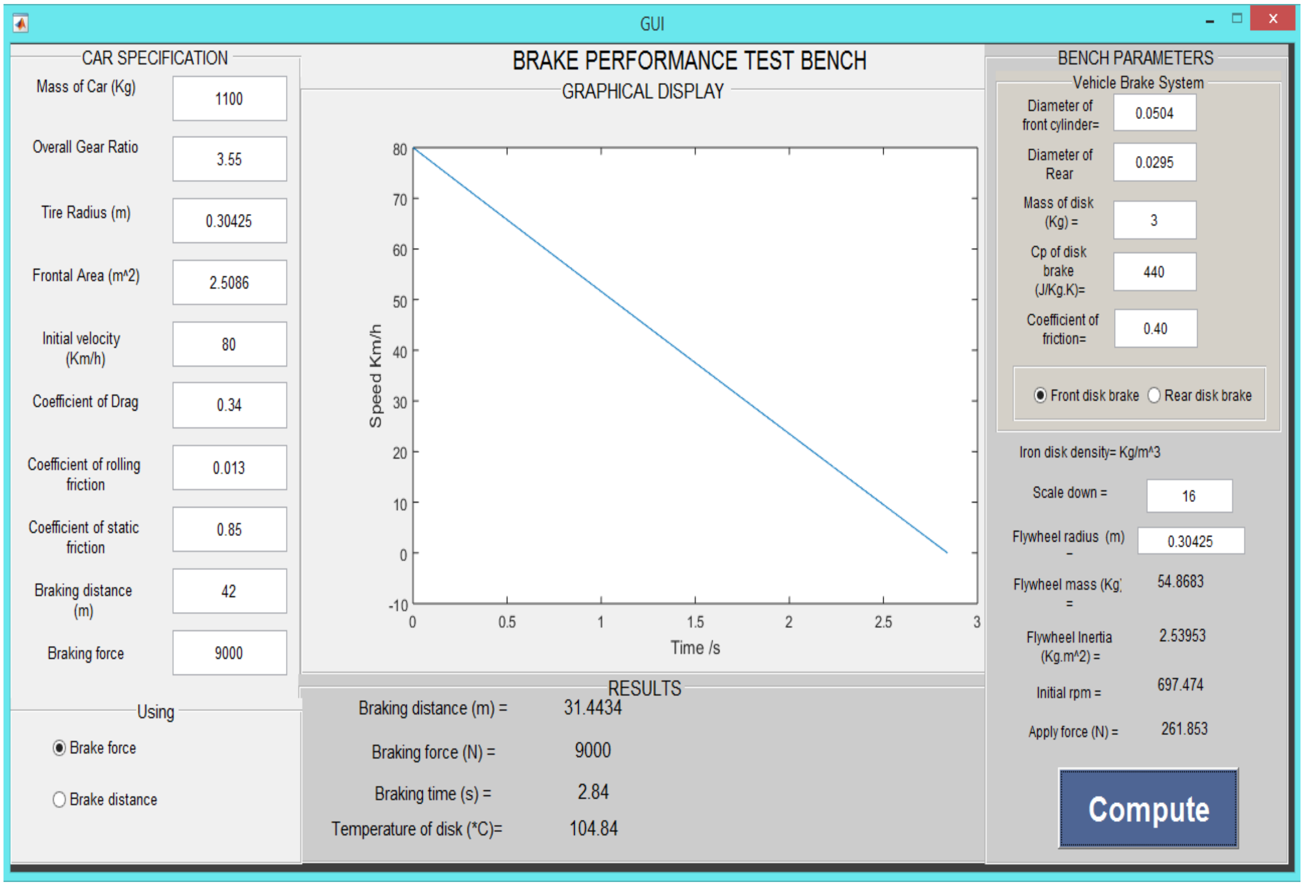


Figure 8: Interface

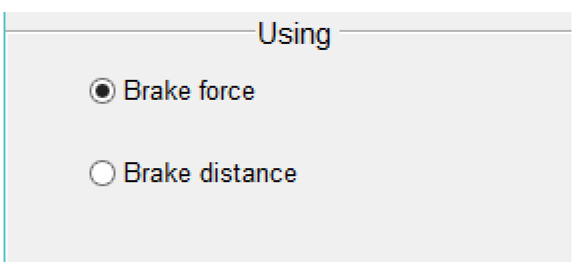


Figure 9: Calculate results for front disk brake or Rear disk brake

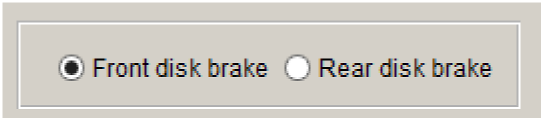
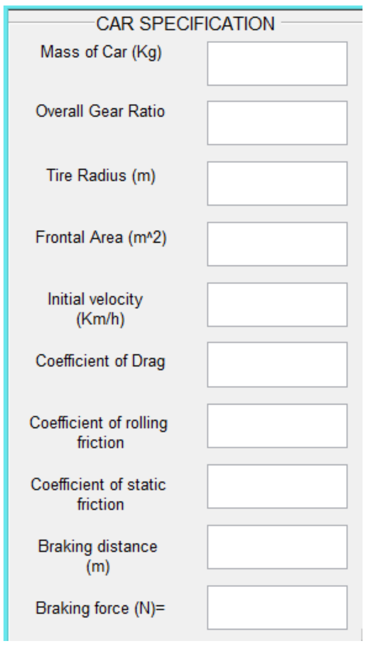


Figure 10

Detailed description



Gear ratio should be of Transmission* Differential.

Initial velocity from which vehicle will be braked.

Typical values of Coefficient of drag range from 0.32-0.4.

Typical value for Coefficient of rolling friction 0.013.

Typical value for Coefficient of static friction 0.85-0.9 depending on road conditions.

Figure 11: Car specification

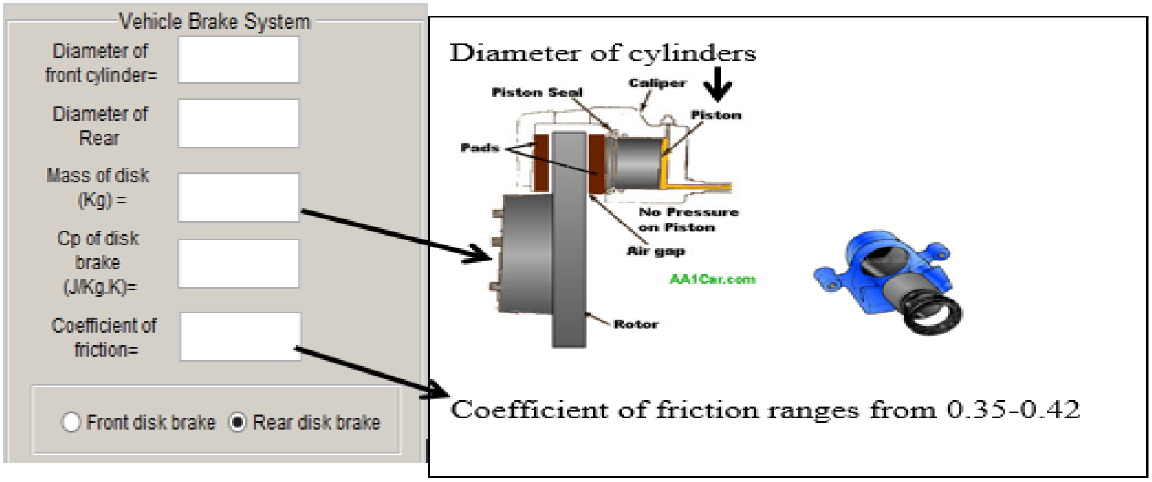


Figure 12: Brake Specifications

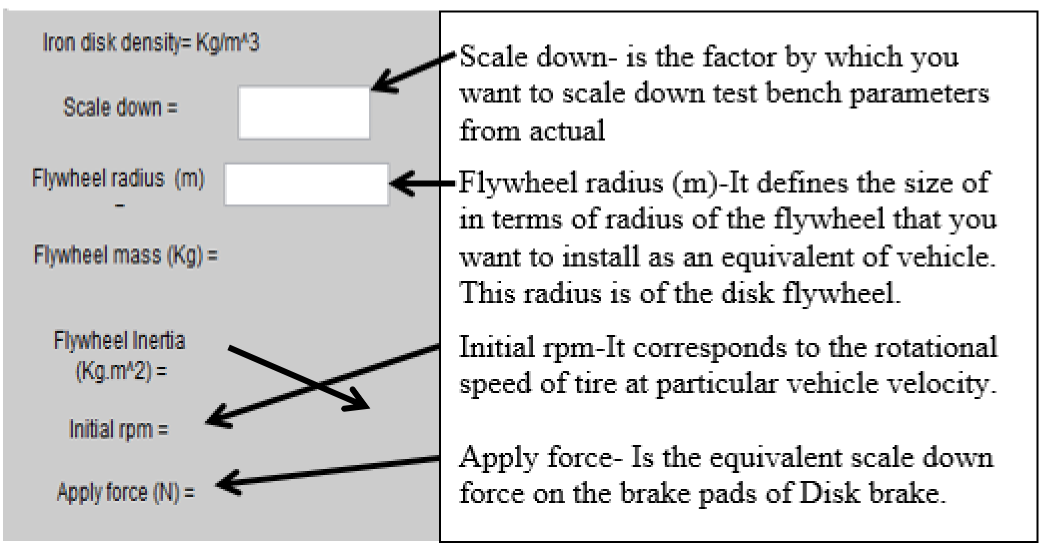


Figure 13: Test Bench

Feature

1. **User friendly**
2. **Graphical Representation**
3. **Easy to learn for a new user**
4. **Self-descriptive**
5. **Fast**

[Code of this software can be found at the end of report]

Solidworks

3D modeling of the prototype is done in Solid works which help us visualize the final product more vividly and allows free of cost alteration and modification to our idea.

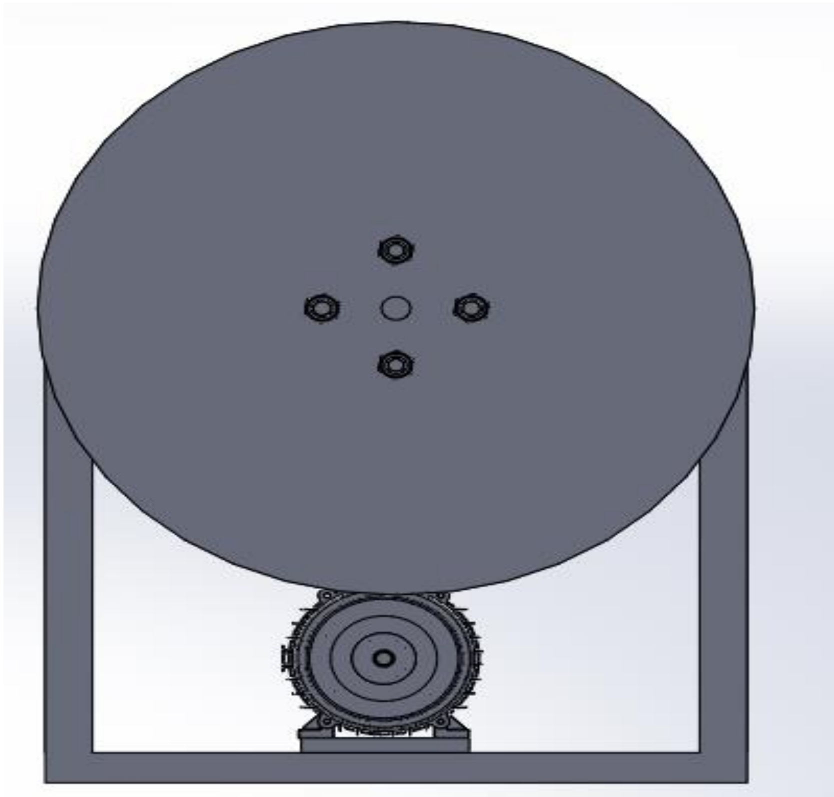


Figure 14: Front View

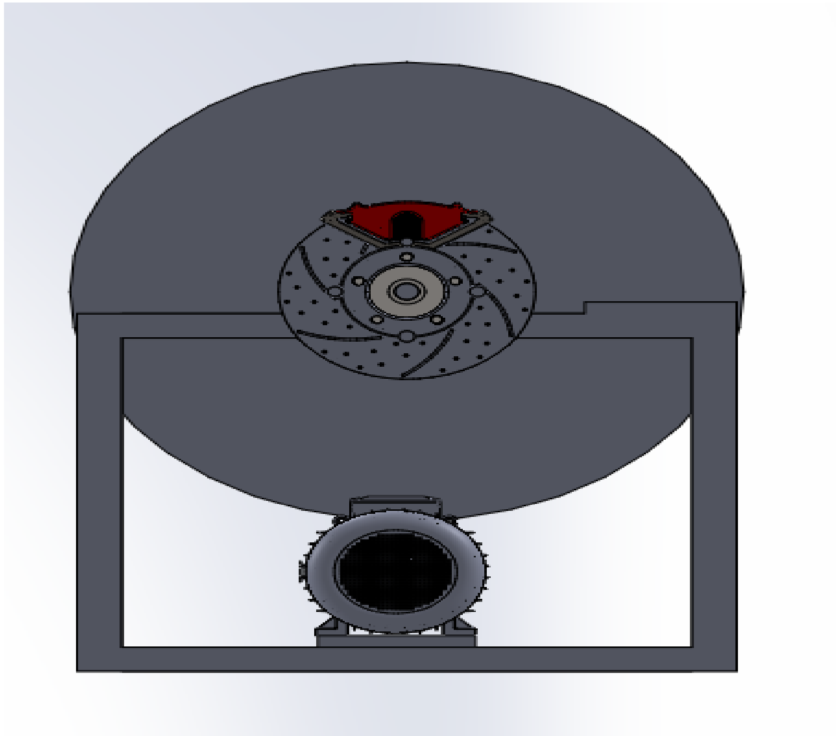


Figure 15: Back View

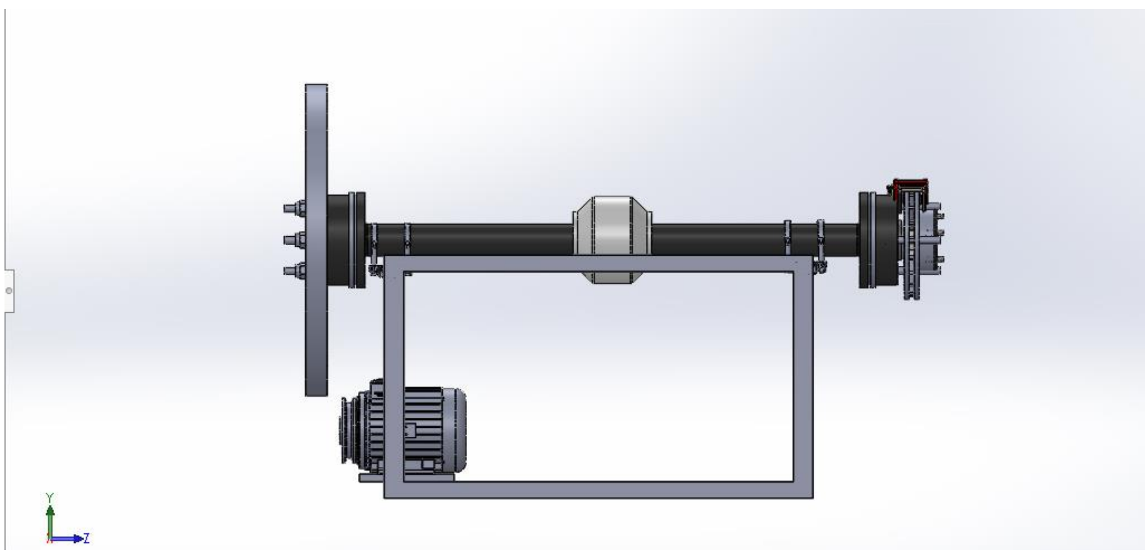


Figure 16: Side View

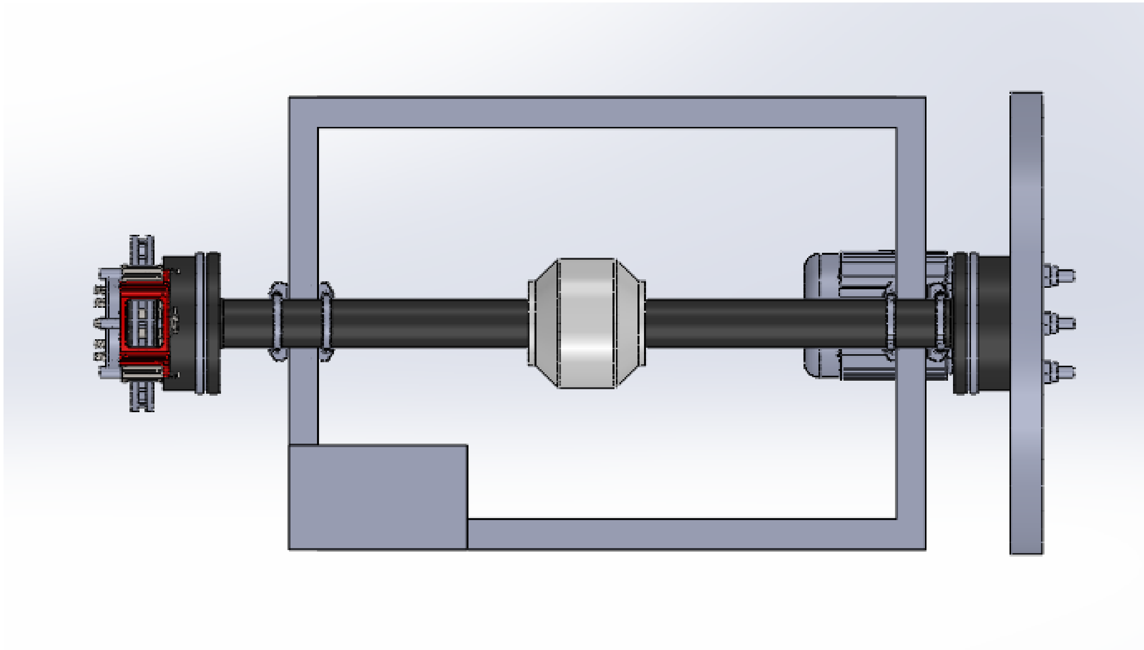


Figure 17: Top View

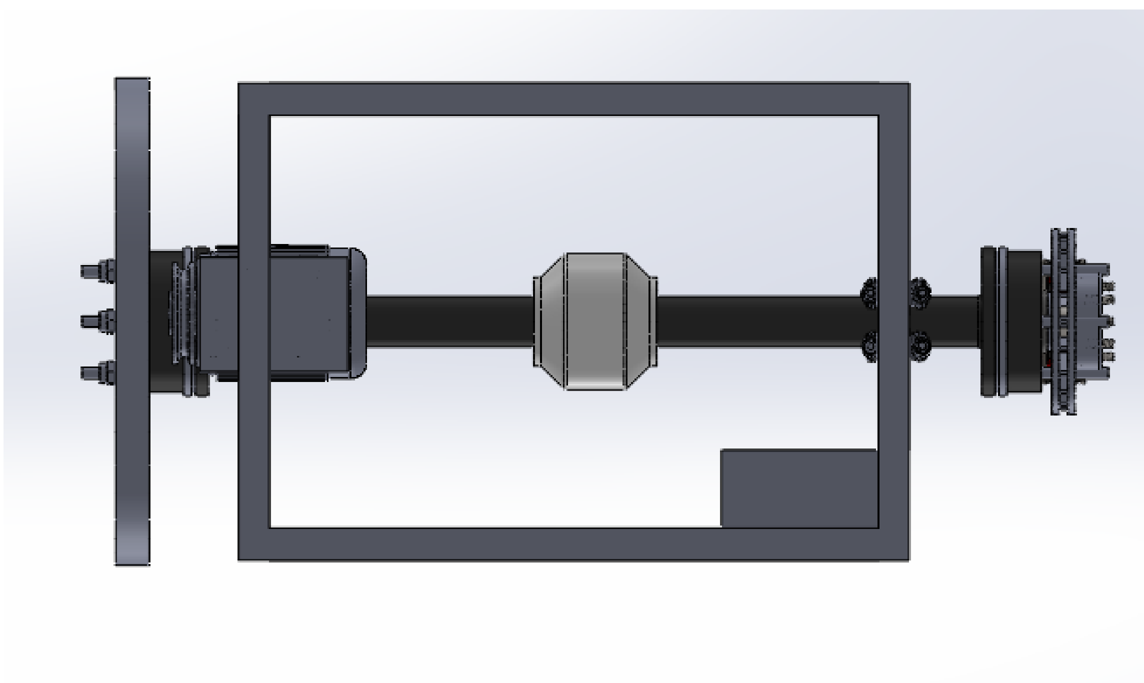


Figure 18: Bottom View

Prototype

The final prototype obtained after going through the series of manufacturing process, assembling and finishing comes out to be

Figure 19: Top View of prototype

Figure 20: Side View (Flywheel and DC motor)

Figure 21: Side View (Disc Brake System)

Figure 22: Brake pedal system and Electrical part

Figure 23: Top View

Operation

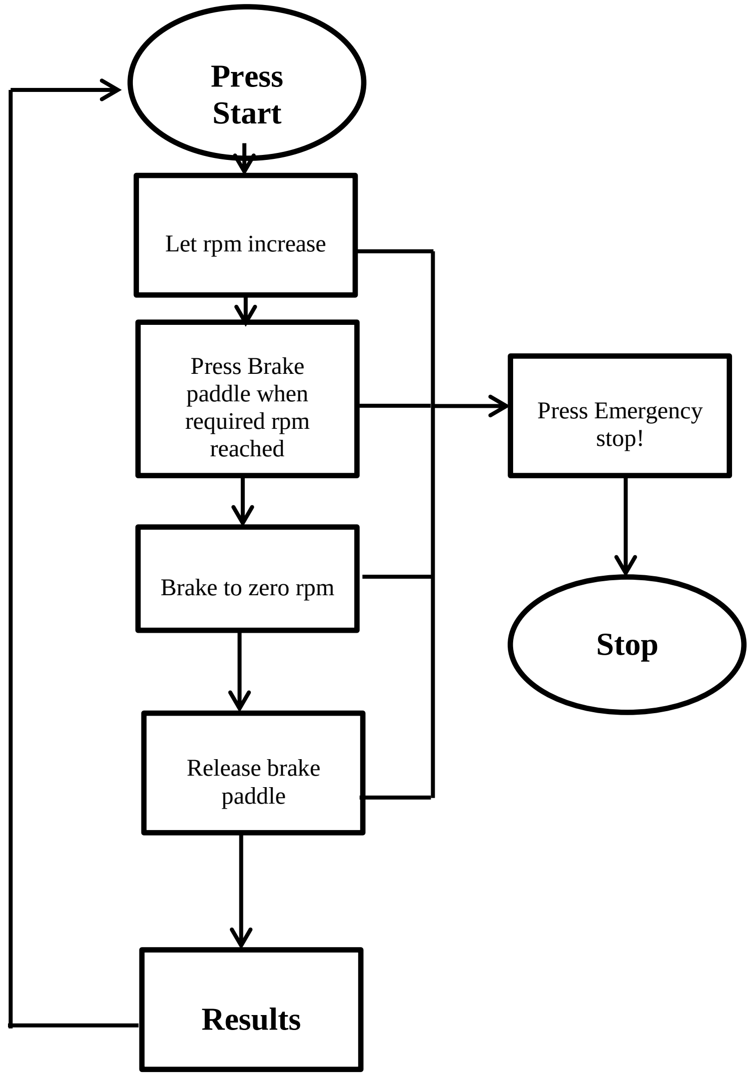


Figure 24 Prototype operation

Electrical

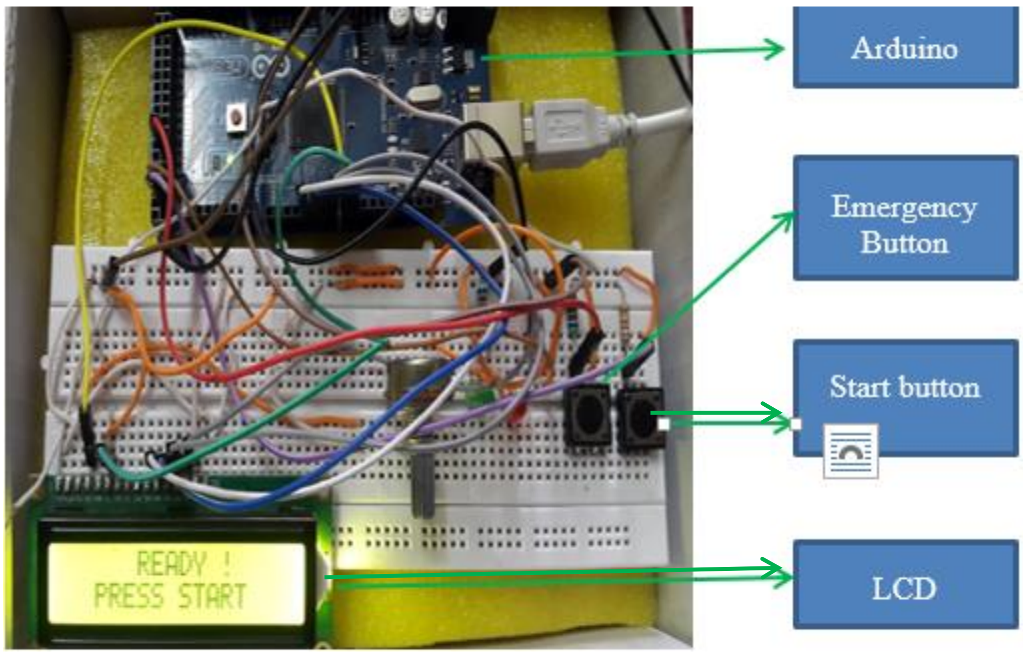


Figure 25: Circuit

Arduino is used to control and process inputs from sensors

Figure 26: Optical Temperature sensor : To measure temperature of brake disk

Figure 27: Infrared sensor: To Measure rpm

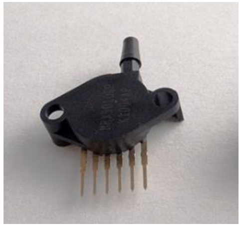


Figure 28: Pressure sensor: To measure brake force

And display on LCD following results

1. Rpm of flywheel
2. Temperature of disk
3. Pressure on brake pads

Figure 29: LCD

Relay will also be controlled by Arduino to control the 3 phase motor that will run the setup.

[Arduino Code can be found at end of this report]

Fabrication

Operations performed

1. Welding
2. Turning
3. Facing
4. Drilling
5. Grinding
6. Electrical Wiring

Parts & details

Table 2: Parts

Serial	Components	Dimensions of components	Qty	Cost (Rs)	Material
1	Motor	2Hp, 3phase	1	8500	--------
2	Shaft	Length=0.6m Diameter>=0.028m	1	100 per kg	Mild Steel
3	Plate	Thickness= 6mm length= 3ft Width=12 cm	1		
4	Bolts	Diameter=0.9 cm length=4 in	4		

5	Bolts	Diameter=1.56 cm length= standard	3		
6	Bearings	Inner Diameter approx. =25mm Qingqi back hub bearing	1		
7	Bolts	Dia=1.2 cm	4		
8	Brake Oil	Car	1		
9	Jumper wires	 0.8 m	6	----	------
10	Axle	Flange to flange length= 1.27m	1	4500	Medium Carbon Steel
11	Force Sensor	http://www.ewallpk.com/sensor-modules/652-flexiforce-pressure-sensor-100lbs.html?search_query=flex&results=27 OR 	1		

12	Motor	3 phase socket & 4 core wire 15 A each length 90in			

CHAPTER 4

RESULTS

Rig Inertia Calculations

R=0.2085m

m=2.5 Kg

Table 3 Inertia calculation results

Height (m)	Time (s)	Acceleration (m/s^2)
55.5	1	1.104
55.2	1	1.104
55.1	0.97	1.173

Acceleration Average=1.127 m/s^2

Angular Acceleration=5.405 rad/s^2

Torque=m*9.81 * R

Torque=5.113 N.m

Inertia=Torque/Angular Acceleration

Inertia=0.94597 Kg.m^2

Rig verification

Curb weight (without a driver):	**1100 kg**
Gearbox:	
Transmission type:	**Manual**

Number of gears:	**5**
Gear ratios (overall):	
I	**3.307 (15.29)**
II	**1.75 (8.09)**
III	**1.171 (5.42)**
IV	**0.923 (4.27)**
V	**0.767 (3.55)**
Standard tires:	**175/65 R 15 S**

Tire Radius=0.30425m

Equivalent mass=mass(1 + 0.04 + 0.0025(G.R)^2)

Front to Rear brake ratio=2.921:1

% of front braking=75

% of rear braking=25

Scaling factor=42.96

Gear ratio= 3.55 (fifth Gear)

Table 4 Results

	Emulation Results (Test Rig)			Software Based Results		
VELOCITY (KM/H)=	**111.7**	**92**	**80.28**	**111.7**	**92**	**80.28**
BRAKE FORCE (N)=	149.63	149.62	186.65	6428	6428	8018.72
BRAKING TIME (SEC)=	5.48	5.11	2.84	5.37	4.471	3.17
BRAKING DISTANCE (METER)=	82.29	54.29	33.93	82.36	55.85	34.06

% ERROR IN

BRAKING TIME= 2.01 12.504 11.619

Percentage error form rig is within 13% which proves validity of test rig.

Graph

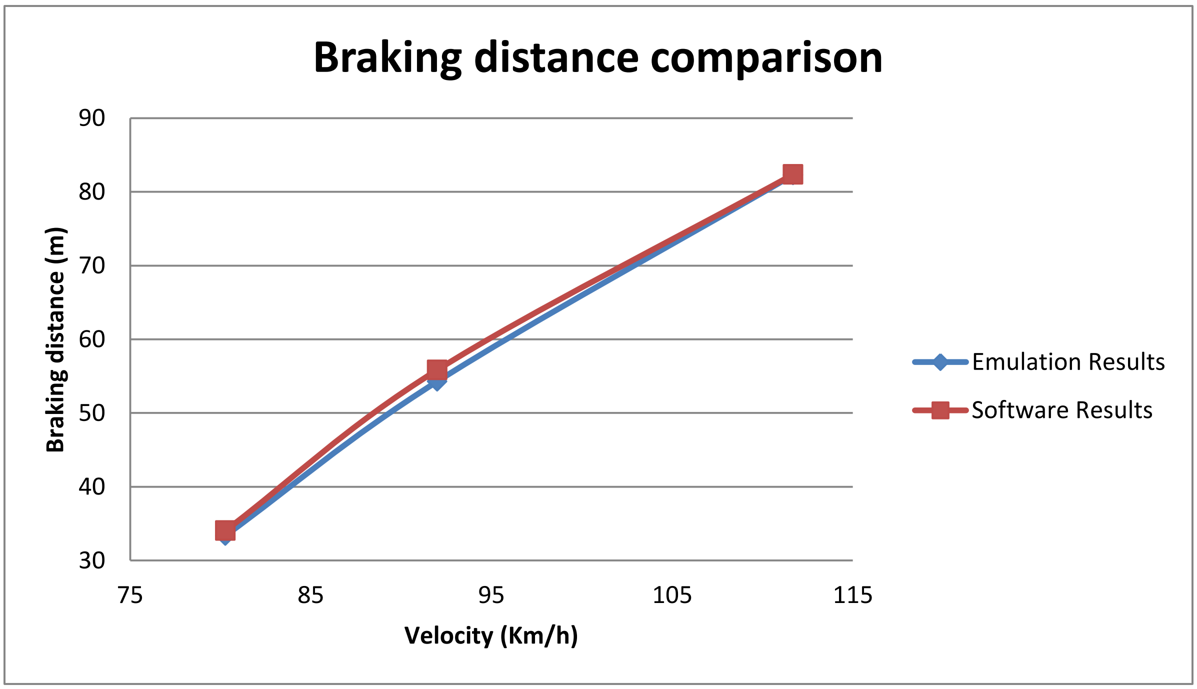


Figure 30 Braking distance comparison

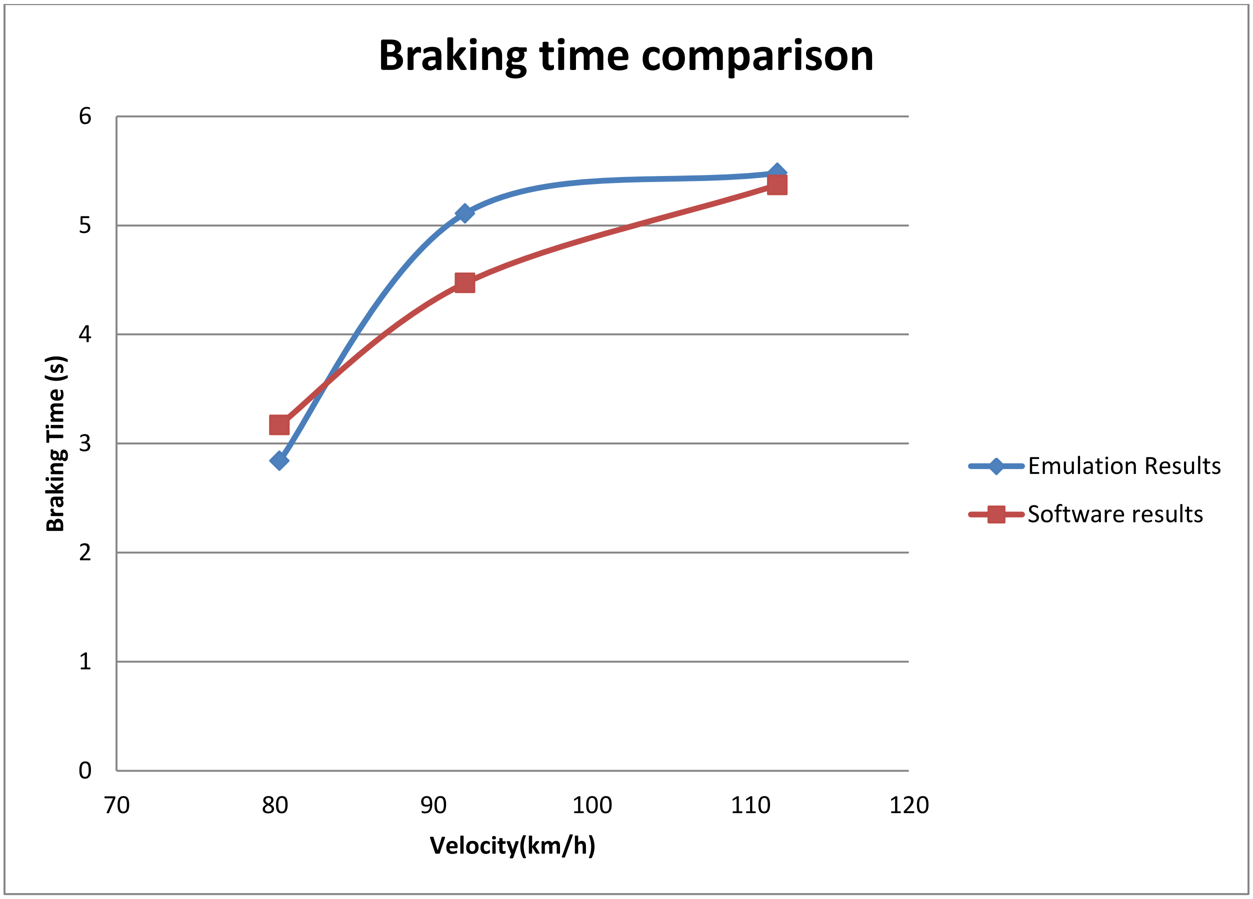


Figure 31 Braking time comparison

Sources of error

1. Friction
2. Instrumental error
3. Manually applying brakes causes fluctuation in readings
4. Vibration in rotating assembly
5. Scaling factor is high (upto 42.96)

CHAPTER 4

CONCLUSION AND RECOMMENDATION

The foot force used to push the brake paddle has disturbance in it because it is applied manually. To address this problem Fluidic Muscle which works pneumatically can be used. The Fluidic Muscle is in line with the load cell. Via the load cell, which is fixed at the brake lever to apply the feet force we can control the process of pushing the lever with a defined force, the Pneumatic valve and the load cell are in a controlling cycle, which are programmed.

In the simulated road test of brake test for brake performance, due to the mechanical inertia, flywheel could not concisely achieve the rotational inertia which test system required, motor can be introduced in the test bench. In order to meet the Inertia requirements to simulate a real vehicle, the current of the motor could be controlled specifically when it participating in the experiments to compensate the energy the mechanical inertia required. Due to the complexity of the brake performance, the precise relationship between the motor driving current and the time is difficult to obtain. The normal method will be discretization. The entire braking time will be discretized into quite a few tiny time periods. Then according to the instantaneous speed and instantaneous torque which observed in previous period, devising the driving current value of the current time. This process successively operated until the completion of brake test.

On the test rig the effects of aerodynamic drag and rolling resistance are ignored which contribute so some error in the results. We can make our bench more accurate by installing a DC motor that will be controlled by a Micro-Controller to provide variable torque that emulates actual vehicle drag and rolling resistance.

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APPENDIX I: TITILE OF APPENDIX I

Arduino Code

```
#include <Wire.h>
#include <Wire.h>
#include <Adafruit_MLX90614.h>

Adafruit_MLX90614 mlx = Adafruit_MLX90614();

volatile byte rpmcount;
unsigned int rpm;
unsigned long timeold;
unsigned long start;
unsigned long hault;
unsigned long distance;
int val1;
int val3;
int val4;
int val5;
int count;
int inertia=0.9831;
int v;
int v1=0;
int countex;
void rpm_fun()
{
  //Each rotation, this interrupt function is run twice, so take that into consideration for
  //calculating RPM
  //Update count
  rpmcount++;
}
int RELAY = 3;
int button1 = 4;
int button3 = 5;
int a0;
int y;
int ledg = 6;
int ledr = 7;
float force = 0;

void setup()
{
  Serial.begin(9600);
  mlx.begin();

  pinMode(RELAY, OUTPUT);
```

```
  digitalWrite(RELAY, HIGH);  // turn Relay off
  pinMode(ledg, OUTPUT);
  pinMode(button1, INPUT);
  pinMode(button3, INPUT);




  digitalWrite(ledg, HIGH);  // turn LED on
  digitalWrite(ledr, LOW);  // turn LED off


  //Interrupt 0 is digital pin 2, so that is where the IR detector is connected
  //Triggers on FALLING (change from HIGH to LOW)
  attachInterrupt(0, rpm_fun, FALLING);

  rpmcount = 0;
  rpm = 0;
  timeold = 0;
  start = 0;
  hault = 0;
  distance = 0;

}



void loop()
{
 delay(500);
  a0 = analogRead(0);
  y= ((a0 * (5.0 / 1023.0))+0.069329-(0.04*5))/(5*0.0012858)-101;

  val1 = digitalRead(button1);  // read input value

  if (val1 == HIGH)
  { // check if the input is HIGH (button pressed)
    digitalWrite(RELAY, LOW);  // turn Relay on
  }
  val3 = digitalRead(button3);  // read input value
  if (val3 == LOW)
  { // check if the input is HIGH (button pressed)
    digitalWrite(RELAY, HIGH);  // turn Relay off
    v=v1;
  }

  if (rpm == 0)
  { // check if the input is HIGH (button pressed)
    digitalWrite(ledg, HIGH);  // turn Relay on
```

```
  digitalWrite(ledr, LOW);  // turn Relay on
 }
 else
 {
  digitalWrite(ledg, LOW);  // turn Relay on
  digitalWrite(ledr, HIGH);  // turn Relay on
 }

 if ((rpm>0) &&  (val3==LOW))
 {
  count=count+1;
 }
 countex=count;
 distance=(v1*v1)*2*(((0.121+0.073)/2 * y*0.504/inertia)*0.30425);

  if (rpm == 0)
 {
  count=0;
 }
//delay(200);


 //Update RPM every second
 //Don't process interrupts during calculations
 detachInterrupt(0);
 //Note that this would be 60*1000/(millis() - timeold)*rpmcount if the interrupt
 //happened once per revolution instead of twice. Other multiples could be used
 //for multi-bladed propellers or fans
 rpm = 30 * 1000 / (millis() - timeold) * rpmcount;
 //Serial.println(rpm);

 timeold = millis();  rpmcount = 0;
 v=rpm*2*3.142/60*0.30425;

 Serial.print("P(kpa)");
Serial.print("\t");
Serial.print("V(m/s)");
Serial.print("\t");
Serial.print("Stop Distance(m)");
Serial.print("\t");
Serial.print("count");
Serial.print("\t");
 Serial.println();
 Serial.print(y);
 Serial.print("\t");
 Serial.print(v);
 Serial.print("\t");
 Serial.print(distance);
```

```
  Serial.print("\t\t\t");
  Serial.print(countex);
  Serial.println();

  //Restart the interrupt processing
  attachInterrupt(0, rpm_fun, FALLING);
//delay(500);
}
```