ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

Design and Development of Braking System for Front Wheel Drive Electric Tadpole Vehicle

[1] Sachin S, [2] Anirudha Betageri, [3] K E Akash, [4] Prajwal M K, [5] Sharanbassappa S. Patil

[1] [2] [3] [4] B.Tech., Department of Mechanical Engineering, PES University, Bangalore, India
[5] Professor and Automotive Domain Lead, Department of Mechanical Engineering, PES University, Bangalore, India
Corresponding Author Email: [1] sachinsmraju@gmail.com, [2] anirudhbetageri16@gmail.com,
[3] keakash1991@gmail.com

Abstract— ***Tadpole type vehicle is one of the rare vehicles in transport system having two wheels at the front and one wheel at the rear. The objective of this project is to design and develop the braking system for tadpole vehicle considering the dynamics of the vehicle. Various parameters required for braking of the vehicle such as static and dynamic loads, braking force required to bring the vehicle to halt, brake torque, and pedal ratio are calculated. The mathematical models using Simulink software are created using the obtained parameters to determine the stopping distance and stopping time of the vehicle. The various parts of braking system were selected from the market whose specifications are closer to our requirements. Modal analysis and thermal analysis of brake disc was carried out to determine the natural frequency and different mode shapes of the brake disc and the temperature distribution on the brake disc respectively. The CAD models were created for the selected parts using Solidworks software. The CAD models are used for reference to assemble the braking system of the tadpole vehicle. The assembly of the braking system for the tadpole vehicle was carried out based on the study of above parameters.***

Index Terms: Braking system, Disc brakes, Dynamic load, Pedal ratio, Tadpole vehicle, Static load, , stopping distance, Stopping time, Torque.

I. INTRODUCTION

A three-wheeler as the name states is a vehicle with three wheels. The Configuration of three-wheeler is divided into two types.

1. Tadpole Configuration
2. Delta Configuration

The tadpole type has two wheels at the front and one wheel at rear. Braking system is one of the most vital parts of an automobile as it is a concern of safety for the driver, passengers and other civilians travelling on the road, so it is essential to develop an effective braking system. Tadpole vehicle is a new trend in the automobile industry as transport/logistics vehicles, used in city for delivery purposes.

Braking system refers to the integration of parts whose work is to decelerate or completely stop the vehicle in motion or to keep the vehicle stationary when it is at rest. It converts the kinetic energy into thermal energy due to friction. The main concept of this project was to develop a working braking system for the tadpole type vehicle. In a hydraulic brake system, when the brake pedal is pressed, force is applied to the master cylinder piston, which then forces fluid from the reservoir into the pressure chamber, creating pressure throughout the entire hydraulic system. The brake caliper will then exert pressure on the brake pads, pressing them up against the brake disc to create friction. This friction will generate brake torque and slows down the vehicle. When the vehicle is decelerated, the vehicle weight is transferred to the front axle, therefore more braking force is required at front wheels to stop the vehicle.

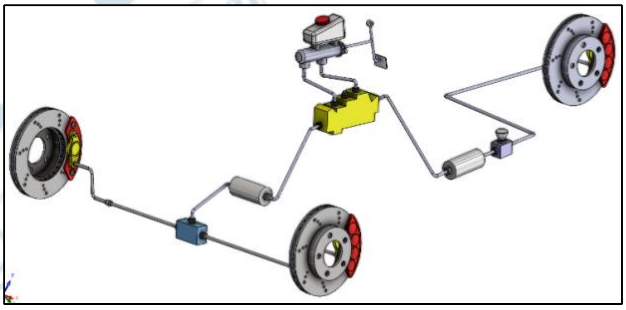

Figure 1: Brake system of Tadpole vehicle

II. METHODOLOGY

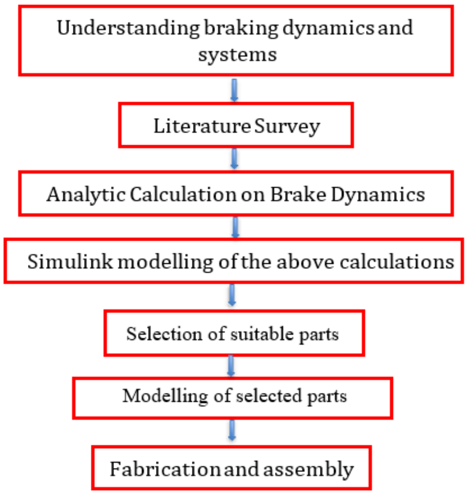

Figure 2: Methodology

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

III. BRAKING DYNAMICS

A. Static Load

The forces acting on a vehicle that does not decelerate, either moving at a constant velocity or stationery is illustrated in Figure3. Due to rear-front weight distribution, the front axle carries significantly higher loads than the rear axle.

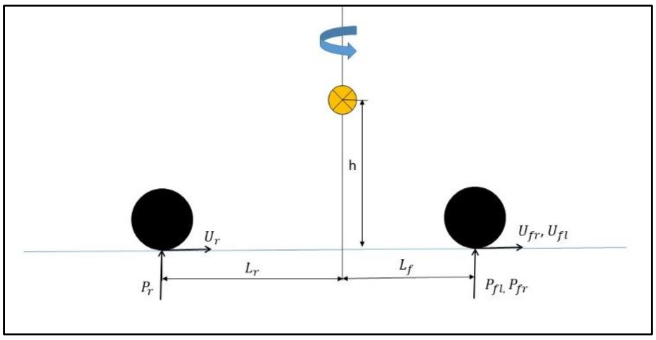

Figure3: Static axle loads

$$F_{zf}+F_{zr} = m \times g \quad (1)$$

$$F_{zr} \times L = m \times g \quad (2)$$

B. Dynamic Load

When the brakes are applied, the brake pads come into contact with the brake disc, the torque which is developed by the wheel brakes is resisted by the circumference of the tire. The braking force is directly proportional to the torque which is generated by the wheel brake before locking.

$$F_{zf,dynamic} = \frac{m \times g \times L_r}{L} + \frac{m \times a \times h}{L} \quad (3)$$

$$F_{zr,dynamic} = \frac{m \times g \times L_f}{L} - \frac{m \times a \times h}{L} \quad (4)$$

C. Brake line pressure

The pressure in the brake hoses depends on master cylinder size and how much force should be applied to the master cylinder via brake lever or pedal. As deceleration increases, the normal force at the rear axle decreases and relatively less pressure is required on the rear brakes in order to prevent the locking of rear brakes before the locking of front brakes. In our case, we have one wheel at the rear due to which the amount of brake line pressure will be high when compared to a four-wheeler.

Torque at the front left = Torque at the front right

$$Torque\ at\ the\ front\ wheel\ (T_{bf}) = \frac{F_{bf}}{2} \times R_w \quad (5)$$

$$Torque\ at\ the\ rear\ wheel\ (T_{br}) = F_{br} \times R_w \quad (6)$$

$$Clamping\ load\ on\ front\ right\ axle = \frac{(T_{bfr})}{r_e \times \mu_1 \times Number\ of\ friction\ faces} \quad (7)$$

$$Clamping\ load\ on\ front\ left\ axle = \frac{(T_{bfl})}{r_e \times \mu_1 \times Number\ of\ friction\ faces} \quad (8)$$

$$Clamping\ load\ on\ rear\ axle = \frac{(T_{br})}{r_e \times \mu_1 \times Number\ of\ friction\ faces} \quad (9)$$

$$Clamping\ Pressure = \frac{clamping\ load}{piston\ area} \quad (10)$$

D. Mechanical Advantage/Pedal Ratio

Pedal Ratio is very crucial during braking. You need to measure the pedal height to the pivot point to determine the pedal ratio and then divide the pivot measurement to the lower arm which controls your rod to the master cylinder.

$$Pedal\ ratio = \frac{Pedal\ force \times Clamping\ Pressure}{area\ of\ master\ cylinder} \quad (11)$$

E. Brake Proportioning

The relationship between front and rear brake forces achieved by applying pressure to each brake and its corresponding gain is defined by the term "brake proportioning." Up until one of the axles locks up, the brake decelerations that can be performed are just the sum of the braking gain (pressure/torque) and level of application. As the brake force on an axle decreases due to lockup, some degree of vehicle control is lost. Bringing both axles to the locking point simultaneously is the optimum design. By adjusting the pressure appropriately based on the brakes fitted on the vehicle, it is possible to match the brake outputs on the front and rear axles. Afterward, proportioning modifies the brake output at the front and rear wheels in accordance with the highest traction forces available. The peak coefficient of friction and immediate load are the main contributors to the highest traction force on the axle. A dynamic load transfer from the rear axle to the front axle occurs throughout the entire deceleration in such a way that the load on the axle is the sum of the contributions from the dynamic load and static load-transfers.

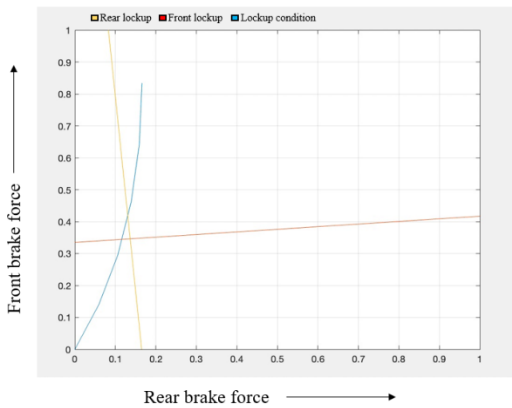

Figure 4: Wheel lockup

In Figure 4, the horizontal axis represents the rear brake force which is proportional to rear brake pressure and the vertical axis represents the front brake force, proportional to front brake pressure in addition with brake gain.

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

The red line denotes the front lockup whereas the yellow line denotes the rear lockup. The front wheel locks up when the car is braked to a level that is above the front brake force limit, which results in the loss of steering control. The rear wheel locks up when the brake pressure exceeds the rear brake force limit, which also throws the car's balance off. The ambiguity requires careful consideration in the design of the brake system because it has safety implications.

IV. SIMULINK MODEL

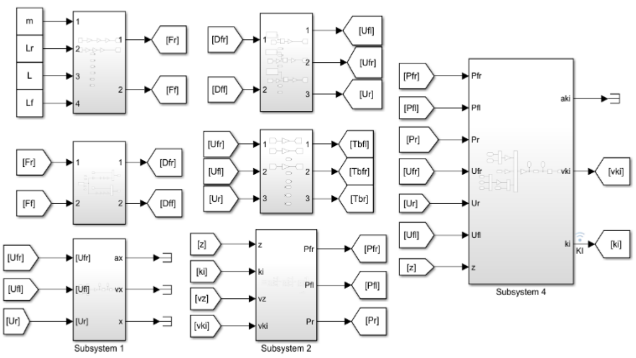

Figure 5: Brake dynamics model

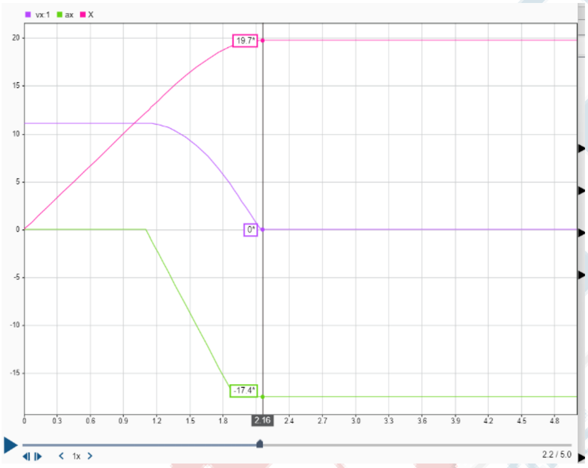

Figure 6: Stopping distance v/s time

The Figure 6 represents the longitudinal displacement with respect to time and in the graph, the pink line indicates the stopping distance which is obtained as 19.7m from initial velocity of 40 kmph to final velocity of 0 kmph indicated by the purple line. The stopping time was obtained as 2.16 seconds

Figure 7: CAD model of brake pedal assembly

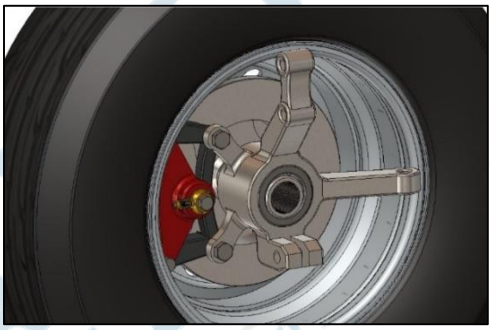

Figure 8: CAD model of front wheel brake assembly

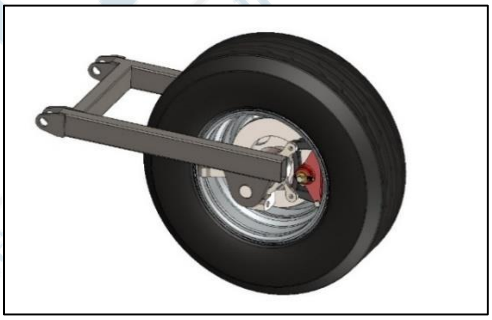

Figure 9: CAD model of rear wheel brake assembly

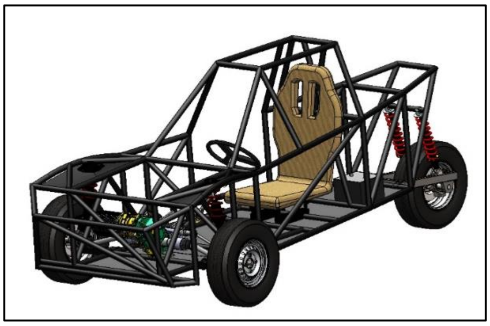

Figure 10: CAD model of vehicle assembly

V. DESIGN AND ANALYSIS OF BRAKE SYSTEM

A. Design of Brake system

The Computer Aided Design (CAD) of various parts of brake system were modelled using Solidworks and the assembly of the whole braking system was done in order to visualize and assist for the fabrication of the vehicle. It is also used for determining the weight of the assembly and also for performing the analysis of the system.

B. Thermal Analysis of Brake Disc

Thermal Analysis for the disk brakes is done for understanding the distribution of temperature which may cause crack initiation and spot melting. When the brakes are applied, friction takes place between the friction pad and the brake disk. These frictional forces oppose the motion of the disk, due to which heat is generated in the disk and it distributes over the disk. The heat generated in the disk is dissipated by different modes of heat transfer like conduction and convection. The analysis was carried out in Ansys workbench where the model from Solid works was imported and meshing of element size 4mm was used. The boundary conditions were given as heat flux on the area swept by brake pad, the modes of heat transfer like conduction, convection and radiation, the coefficient of conduction of cast iron, film coefficient of convection and atmospheric temperature were taken into account.[10]

Average braking power at wheel $[q_{(o)}]$:

$$q_o = \frac{K(1-s) \times u \times a \times W \times 3600}{2(778)} \quad (12)$$

$$q_{(o)} = 0.7 \times 0.5 \times 0.9 \times q_o \quad (13)$$

where,

$0.70 = weight\ distribution\ on\ front\ axle$

$0.50 = since\ one\ front\ brake\ rotor\ is\ considered$

$0.90 = 10\%\ heat\ loss\ (Heat\ loss\ coefficient)$

$$Swept\ Area\ of\ Disc\ Rotor\ = \frac{\pi}{4}(D^2 - d^2) \quad (14)$$

$$\text{Final braking power in } \left(\frac{Nm}{s}\right) = \frac{q_{(o)}}{t} \quad (15)$$

$$\text{Heat flux(H) in } \left(\frac{\text{W}}{m^2}\right) = \frac{Power}{Area} \quad (16)$$

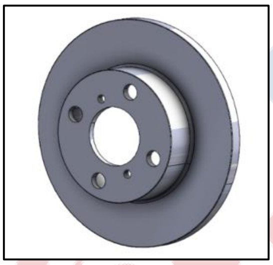

Figure 11: CAD model of brake disc

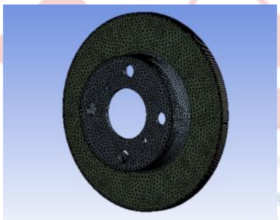

Figure 12: Meshing

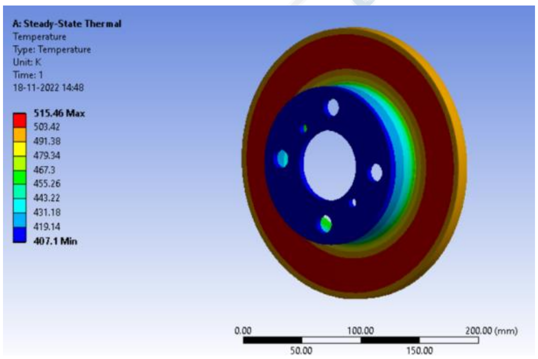

Figure 13: Temperature distribution on Front Disc

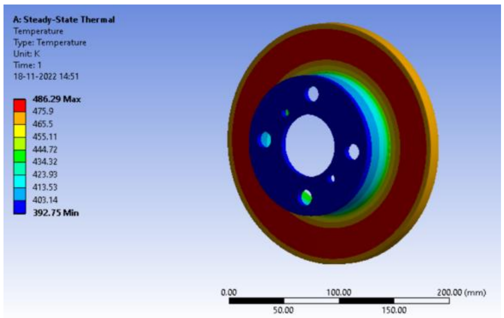

Figure 14: Temperature distribution on Rear Disc

From the thermal analysis done on the brake disc, the temperature distribution on the font disc ranges from 515.46K to 407.1K as shown in Figure 13 and on the rear disc, it ranges from 486.29K to 392.75K as shown in Figure 14.

C. Modal Analysis of Brake Disc

The Modal Analysis on the Disc Brake is carried out to find the system's dynamic behaviour i.e., natural frequencies and mode shapes. The objective of performing modal analysis for a component is to obtain natural frequencies which should not fall under the frequency range of vibration source and road excitation frequency. The analysis was carried out in Ansys Workbench in which the three-dimensional model of brake disc was imported and meshing of 4mm element size was carried out on the disc. The brake disc assembly was examined considering free-free boundary conditions which allows the component to vibrate freely without any interference of other components.

Mode shapes of the Brake disc

Table 1: Natural frequencies of disc

Mode	Frequency [Hz]
1	1422.2
2	1422.8
3	1634.9
4	1650.3
5	1900.1
6	2667.5

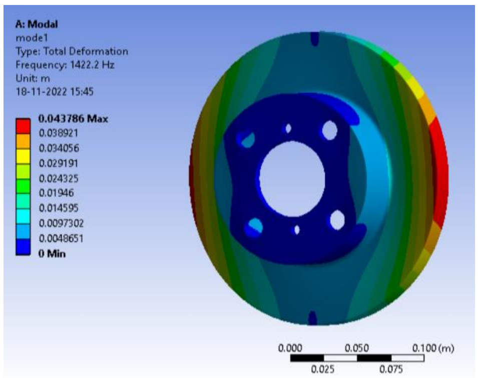

Figure 15: 1st mode

IFERP
connecting engineers... developing research

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 10, Issue 5, May 2023

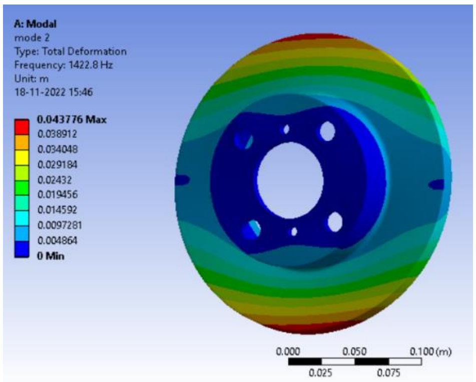

Figure 16: 2nd mode

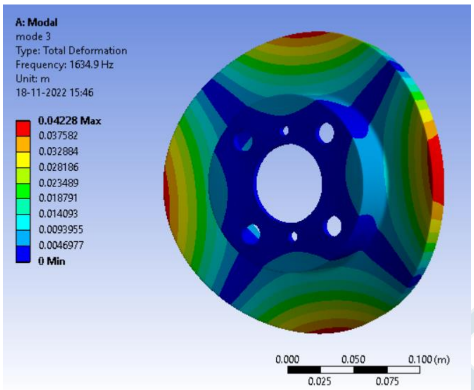

Figure 17: 3rd mode

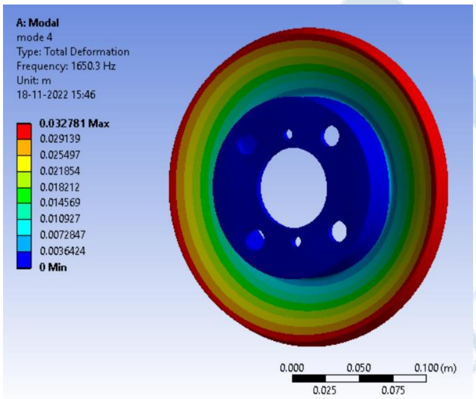

Figure 18: 4th mode

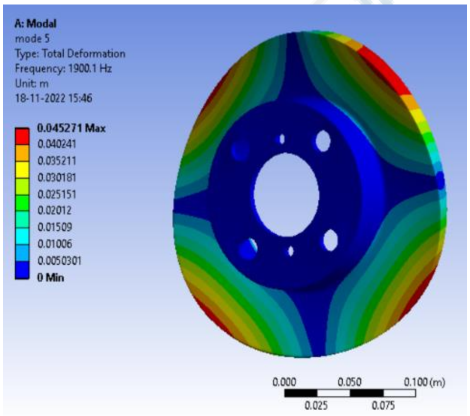

Figure 19: 5th mode

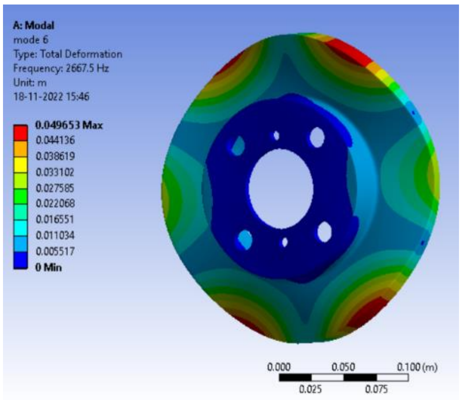

Figure 20: 6th mode

The natural frequency and the mode shapes of the brake disc are determined using the modal analysis and the natural frequencies of different modes are shown in the figures above. The frequencies of the brake disc are greater than that of frequency generated by the vehicle. Hence the selected disc is safe and do not fail under dynamic conditions.

VI. RESULTS

Table 2: Vehicle design parameters

Gross weight of the vehicle	450kg
Weight distribution (front: rear)	0.67:0.33
Wheelbase	2.438m
C.G. Height	0.4
Number of wheels on front axle	2
Number of wheels on rear axle	1
Vehicle Deceleration	0.45g
Tire radius	0.268m

The following results were obtained from the analytic calculations and Simulink models. For an efficient braking system for the design of the tadpole vehicle, using the parameters as stated in the table 2, the required braking parameters are calculated and the results obtained are tabulated in table 3. Using these parameters, the different braking system parts are selected based on our requirements. The modelling of the different braking parts was carried out and the thermal and modal analysis for brake disc was performed.

Table 3: Brake Dynamic results

Static force at Front	2944.21N
Static force at Rear	1470.29N
Dynamic force at Front	3270.13N
Dynamic force at Rear	1144.4N
Torque at Front	350.55Nm
Torque at Rear	245.35Nm
Front Clamping load	4906.91N

Rear Clamping load	3434.35N
Front line Pressure	2.40Mpa
Rear line Pressure	1.68Mpa
Pedal Ratio	2.26
Stopping Distance	19.7m

The results of the thermal analysis indicates that the temperature distribution on the font disc ranges from 515.46K to 407.1K and on the rear disc, it ranges from 486.29K to 392.75K and is found to be safe for the vehicle's performance. The results of the modal analysis indicates that the brake disc can withstand the natural frequency of the vehicle and also the road excitation frequency and hence is safe to use. The various parts of the brake system were purchased and assembled accordingly on the tadpole vehicle.

Figure 21: Brake assembly at front and rear

The front and rear wheel assembly including the braking system are shown in the fig 21. After the assembly of the tadpole vehicle, the brake bleeding was carried out to transfer the brake fluid equally in all brake callipers and to remove the entrapped air in the brake hoses for the proper actuation of the brakes to ensure smooth braking.

Figure 22: Brake Pedal and Master Cylinder Assembly

Figure 23: Vehicle Assembly

The Figure 23 shows the complete assembly of the tadpole vehicle consisting of all the systems like chassis, braking system, powertrain, suspension system etc.

VII. CONCLUSION

An effective braking system for the front wheel drive tadpole type electric vehicle has been successfully developed. Initially, the case study on various braking dynamics involved during braking were studied and based on the study various braking dynamic calculations were carried out. Based on the results obtained, various braking parts were selected which suited our vehicle requirements, design of the same was carried out. For the brake disc, thermal and modal analyses were performed to evaluate how well it will work under the conditions of our vehicle. The various braking parts were purchased and assembled during the fabrication of the tadpole vehicle. Multiple test runs were carried out to assess the effectiveness of the braking system.

VIII. SCOPE FOR FUTURE WORK

- Design and implementation of Anti-lock braking system for tadpole type electric vehicle.
- Design and development of regenerative braking system for tadpole type vehicle.
- Implementation of electrohydraulic brake-by-wire system for tadpole vehicle.

REFERENCES

[1] Aleem, M. A., Saad, A. A., Sohail, A., Siraj, S. M., & Reddy, M. R. (2018). Design And Analysis of Drum Brakes. *International Journal of Advanced Technology and Innovative Research*, *10*(4), 348-354.

[2] Maluf, O., Angeloni, M., Milan, M. T., Spinelli, D., & Bose Filho, W. W. (2007). Development of materials for automotive disc brakes. *Minerva*, *4*(2), 149-158.

[3] Fu, C. Q., Wang, Z., Li, B., & Yu, C. (2010). The Dynamics Simulation of Braking Process on Automobile Disc Brake. In *Advanced Materials Research* (Vol. 139, pp. 2658- 2661). Trans Tech Publications Ltd.

[4] Sabri, M., & Fauza, A. (2018, February). Analysis of vehicle braking behavior and distance stopping. In *IOP Conference Series: Materials Science and Engineering* (Vol. 309, No. 1, p. 012020). IOP Publishing.
[5] Huston, J. C., Graves, B. J., & Johnson, D. B. (1982). Three wheeled vehicle dynamics. *SAE Transactions*, 591-604.
[6] Belhocine, A., & Bouchetara, M. (2012). Thermal analysis of a solid brake disc. *Applied thermal engineering*, *32*, 59-67.
[7] Sunday, B., Thomas, U., Ityokumbul, I. S., & Nasir, A. (2019). Effect of Number of Passengers [Loading] on Centre of Gravity of a Three Wheeled Vehicle [Keke- Napep]. *Arid Zone Journal of Engineering, Technology and Environment*, *15*(3), 638-647.
[8] Ahn, J. K., Jung, K. H., Kim, D. H., Jin, H. B., Kim, H. S., & Hwang, S. H. (2009). Analysis of a regenerative braking system for hybrid electric vehicles using an electro-mechanical brake. *International Journal of Automotive Technology*, *10*(2), 229-234.
[9] Nantais, N. C. (2006). Active brake proportioning and its effects on safety and performance.
[10] Dhir, D. K. (2018). Thermo-mechanical performance of automotive disc brakes. *Materials Today: Proceedings*, *5*(1), 1864-1871.
[11] Lordache, A. A., Anghelache, G., & Moisescu, R. (2018). Brake disc modal behavior. *University of Pitesti. Scientific Bulletin-Automotive Series*, *28*(1).
[12] Mo, J. O. (2021). Numerical and experimental investigation of compressible-brake-fluid flow characteristics and brake-bleeding performance in EPB caliper. *International Journal of Automotive Technology*, *22*(2), 315-325.
[13] Vishesh Bhatt, Gaurav Nakhat, 2021, Braking Calculation for a BAJA ATV, *International Journal of Engineering Research & Technology* (IJERT) Volume 10, Issue 04 (April 2021),
[14] Limpert, R. (2011). *Brake design and safety* (pp. i-xv). SAE.
[15] Shahril, A., Samin, R., Juraidi, J. M., & Daut, J. (2015). Structural analysis of brake disc using dynamic simulation. *ARPN J. Eng. Appl. Sci*, *10*(17), 7805-7808.
[16] Prasad, A., Gupta, S. S., & Tyagi, R. K. (Eds.). (2019). *Advances in Engineering Design: Select Proceedings of FLAME 2018*. Springer.

NOMENCLATURE

L = Wheelbase
F_{zf} = Static load at front axle
F_{zr} = Static load at rear axle
$F_{zf,dynamic}$ = Dynamic load at front axle
$F_{zr,dynamic}$ = Dynamic load at rear axle
F_{bfl} = Braking force at front left axle
F_{bfr} = Braking force at front right axle
F_{br} = Braking force at rear axle
T_{bfl} = Brake torque at front left axle
T_{bfr} = Brake torque at front right axle
T_{br} = Brake torque at rear axle
V = initial velocity
U = final velocity
s = stopping distance
r_e = Effective radius
U_{fr} = Longitudnal force acting on front right axle
U_{fl} = Longitudnal force acting on front left axle
U_r = Longitudnal force acting on rear axle
P_{fr} = Vertical force acting on front right axle
P_{fl} = Vertical force acting on front left axle
P_r = Vertical force acting on rear axle
I_{YY} = Pitching moment of inertia
μ=Coefficient of friction between road surface and wheel
μ_r=Coeffficient of rolling resistance
μ_1= Coefficient of friction between brake pad and disc surface
q_o= Average braking power in Watt $q_{(o)}$ = average braking power absorbed per hour by one half or one side of one of the front brakes
S= tire slip = 0.08
H=Heat flux