Design, Fabrication and Analysis of Chassis for Electric Bike

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Abstract

Automobile sector started shifting its dependency from fossil fuel to electrical energy for the last few decades to mitigate the adverse environmental scenario like global warming, air pollution etc. Due to this, battery is emerging as the new source of power. At the same time, use of bikes for city transportation has been growing at a high rate in developed countries. For a heavily congested mega city like Dhaka, electric bikes can provide a better alternative to traditional fossil fuel vehicles. They are not only cost effective but also faster and can contribute to improved public health outcomes. With such background study, an initiative was taken to fabricate an electric bike. This paper presents a study of its chassis design and analysis. Triangulation was used as the basis of the design since this concept provides the best structural strength. Mechanical properties such as stress, strain and deformation at critical locations within the fabricated chassis was compared with numerical results obtained from the state-of-the-art FEA software ANSYS. The validated numerical method allowed to simulate the dynamic performance of the chassis by predicting the forces on the structural member during acceleration and braking. It is expected that the developed numerical methodology will allow to conduct exploratory designs with confidence.

Keywords
Global warming, Electric bike, Chassis, Triangulation, ANSYS.

1. Introduction
The need for alternative fuel vehicles emerged in the 1960s and 1970s due to the increased pollution from internal combustion engines, rising prices, reliance on crude oil, and its diminishing supply. Since then, significant efforts have been made to develop workable electric vehicles to replace present IC engine vehicles. The key challenges that must be addressed to increase the vehicle's range, speed, and payload are weight reduction, analysis methodologies, fabrication processes, and optimization approaches. Topology optimization, based on the removal of conflicting constraints, design clearance, and material defects can be an effective approach for obtaining a lower weight vehicle with maximum performance.

Chassis serves as the vehicle's skeleton, on which various components are mounted so that they can carry out their intended functions. The power-generating components (IC engine for a traditional fossil-fuel vehicle, batteries for an electric vehicle) are installed on the chassis in such a way that they remain protected during accident while also guaranteeing that their smooth operation is not hampered. The chassis accommodates the rider as well as provides hinge points for both front and rear suspension. It must be able to withstand a variety of forces and torques caused by bumping, braking and acceleration.

Centralization and weight reduction of the chassis improve the vehicle's handling and performance. Under typical operating conditions, it is susceptible to dynamic forces transferred from the front and rear suspensions. During its service life, it will also be subjected to time-varying loads which can lead to fatigue failure. In the design and optimization of a motorcycle chassis, the weight must be minimized and centralized while factors such as strength, stiffness and durability should meet the design targets.

An effective design is one that efficiently accomplishes the required task and is safe under extreme operating conditions. At the same time, it must be cost-effective in terms of the materials used and the manufacturing methods. For both failures and redundancies, analysis makes it easier to understand how a component will behave throughout a specific loading cycle. Analysis provides us with a mathematical model which indicates scope for optimization and weight reduction for an overdesigned component.

2. Literature Review

Foale (2002) presented design rules and theories that may be used to build and fabricate a motorbike chassis. He focused on the numerous geometries connected with frame construction, as well as the various forces and moments acting on the frame and other vehicle systems during dynamic behavioral circumstances like as acceleration, braking, and cornering. The author explored the uses and applications of a variety of materials and motorcycle chassis cross-section varieties and various manufacturing techniques.

Cossalter (2006) depicted the evolution of motorcycle chassis during the previous two decades. His empirically developed alternate motorbike formats were executed flawlessly. He proved the importance of varying fork angles and trails in providing different steering geometry dimensions. He proved that the "traditional" rake and trail figures may diverge without difficulty - a claim backed by a pair of experiments carried out by the author himself on a BMW R75, in which rake values as low as zero (vertical forks) and trail dimensions ranging from 50 to 100 mm were tried.

Zeinkiewicz, Taylor and Zhu (2005) presented the mathematical modeling of the component under consideration, with a focus on mesh generation and mesh relevance parameters. Their work serves as a foundation for the development of a finite element analysis (FEA) method for steering knuckle optimization.

SaurabhRege (2017) targeted constructing the frame of a two-wheeled, two-seater motorbike for electric mobility while taking into account the vehicle's strength, safety, and optimal performance. A two-step approach was used to conduct the research. Modeling of the frame according to structural and ergonomic considerations, design restrictions imposed by the front and rear suspension, steering and transmission systems and assemblies, as well as the assessment of loads operating on the frame were all part of the first phase 25. The second step involved stress analysis with finite element analysis tools and design changes to reduce weight without compromising structural strength. The displacement during the worst load scenarios was well within limitations, according to the research. The essential components like the battery pack and the motor were safe from the critical forces acting on the frame.

Abagnale (2016) designed a system basing on the longitudinal vehicle dynamics and the electrical motor. Differently from a common approach in which the electric motor is located on one of the three hubs of the e- bike, the idea of the pedicel prototype presented in the paper consisted of an electrical motor in the central position that transmitted the torque on the central hub.

Irfanudeen et al. (2004) studied about the chassis of mountain bikes and then designed the chassis with low cost that satisfied all the conditions of users. They performed structural and dynamic analysis of the designed chassis in regards to composite materials composed of epoxy resin matrix and kevlar and polycyanate fiber.

3. Methodology

The chosen methodology for this thesis project is shown below in figure 1:

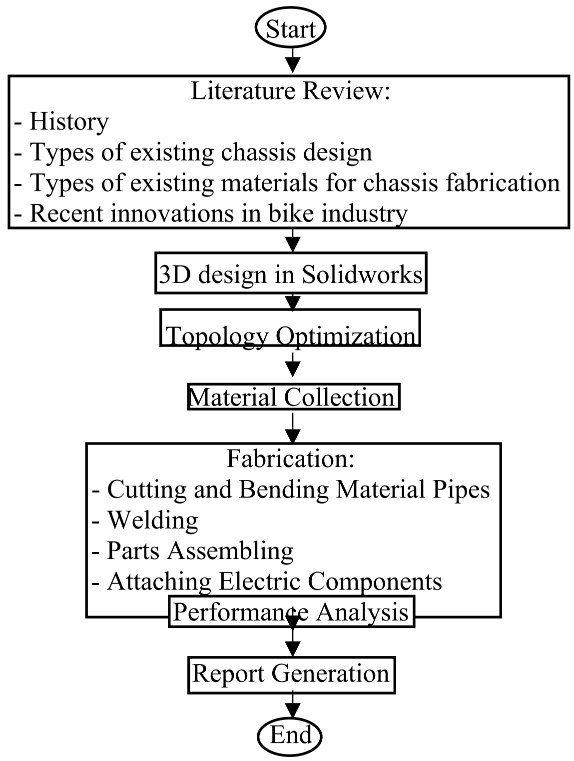


Figure 1. Methodology

4. Calculation of Forces on Motorcycle

4.1 Hypothesis

Several assumptions will be considered while analyzing the forces applied on the motorcycle:
Although bikes are made up of a wide range of mechanical components, we will consider rigid suspensions and define the motorcycle as a spatial mechanism made up of four rigid bodies:

- The rear assembly (chassis, saddle and motor-transmission drive train).
- The front assembly (fork, steering head and handlebars).
- The front wheel.
- The rear wheel.

- All forces applied to the wheels will have direct impact on the chassis. It is true that obtained values will be much higher than normal conditions because suspensions are considered not to be working. So, security coefficient will be lower than normal but the chassis will be evaluated in higher extreme conditions. If it's safe in these conditions, safety in normal conditions will be ensured automatically.
- All masses are considered to be concentrated on the motorcycle's barycenter point. The barycentre of the motorbike is considered to be the barycentre of the chassis.
- The forces from rear wheel act directly on the chassis. There is no connecting rod between shock absorber, swing arm and chassis.
- The center of gravity can't be fixed because the rider position moves continuously during driving. During acceleration, majority of the load is transferred to the rear part while during braking, majority of the load gets transferred to the front part. For our thesis project, we will consider fixed center of gravity.
- We will disregard the center of pressure and the drag force acting on the moving bike.

- The weight of the rider will not be considered during calculation because it varies too much from the dynamic points of view.

- The floor will be considered plane and in good conditions. So, bumping forces produced by irregularities on the road will not be taken into account.

4.2 Bike Parameters

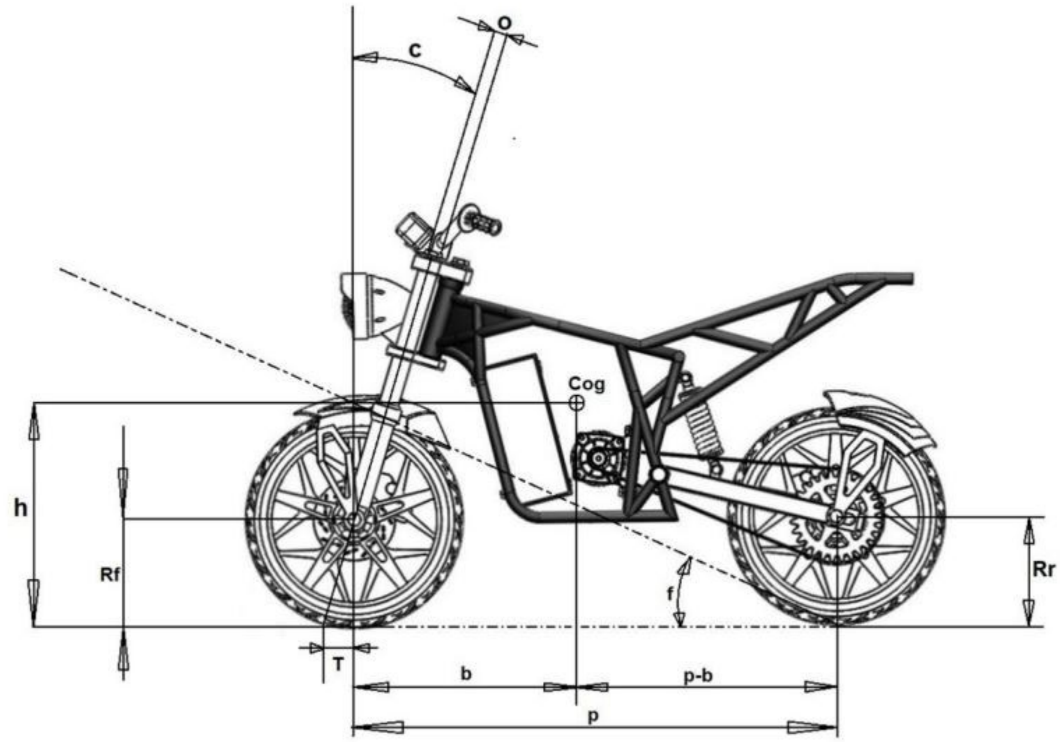


Figure 2: Bike schematics with different geometric parameters

Symbol	Parameter	Numerical Value
p	Wheelbase	833 mm
b	CoG to front	373 mm
p-b	CoG to rear	460 mm
Rf	Front wheel radius	188 mm
Rr	Rear wheel radius	188 mm
h	CoG height	331 mm
c	Caster angle	17°
T	Trail	67 mm
f	Load transfer angle	25°

For performing the analysis of the chassis, Mild Steel (AISI 1020) is used. The weight of the bike is considered to be acting downward from CoG and its value is = m X g = 85 X 9.81 = 833.85 N (Figure 2)

4.3 Forces acting on the bike during maximum acceleration

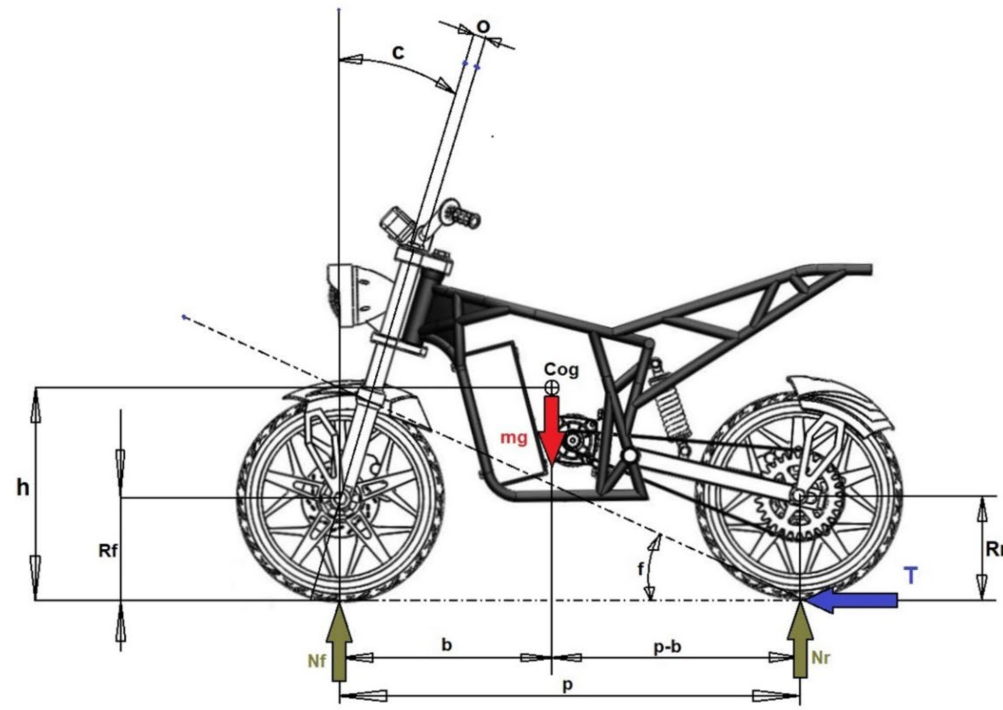


Figure 3. External forces acting on the bike during maximum acceleration

Now, $\Sigma Fy = 0$;

$\therefore mg - N_f - N_r = 0$

Taking moments about CoG,

$\curvearrowright + \quad N_f \times b - N_r \times (p-b) + T \times h = 0$

$\Rightarrow N_f = \frac{Nr \times (p-b) - T \times h}{b}$

$\Rightarrow N_f = \frac{\{(mg-Nf)(p-b)\} - T \times h}{b}$

$\Rightarrow N_f \times b = mg\,(p-b) - Nf\,(p-b) - T \times h$

$\Rightarrow N_f \times b + Nf\,(p-b) = mg\,(p-b) - T \times h$

$\Rightarrow N_f = \frac{mg\,(p-b) - T \times h}{p}$

Since, during maximum acceleration, (Figure 3)

$N_f = 0$

$\Rightarrow \frac{mg\,(p-b) - T \times h}{p} = 0$

$\Rightarrow mg\,(p-b) - T \times h = 0$

$\Rightarrow T = \frac{mg\,(p-b)}{h} = 1158.824\ N \qquad [\because mg = Nr = 85 \times 9.81 = 833.85\ N]$

Chain force is considered during maximum acceleration so that force transmission can be calculated accurately. Contact forces from the floor against the rear tire are transmitted to the chassis through wheel, swing arm and bearings. The points of application of these forces to the chassis are both steering bearings. Steering axle is kept fixed and the forces are transmitted to the chassis via swing arm axle (Figure 4 and figure 5).

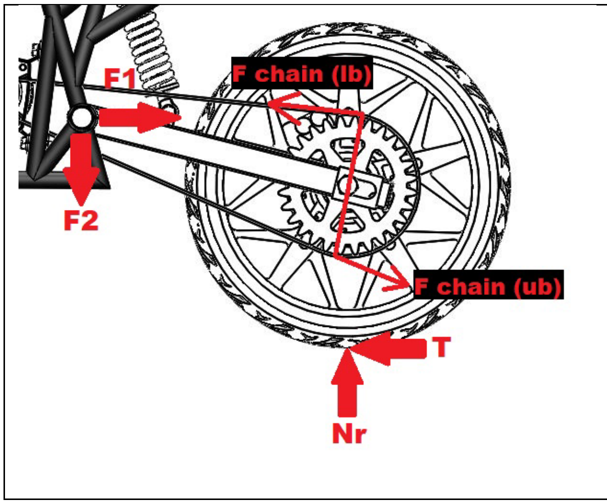


Figure 4. Forces acting on swing arm axle and chain forces during maximum acceleration

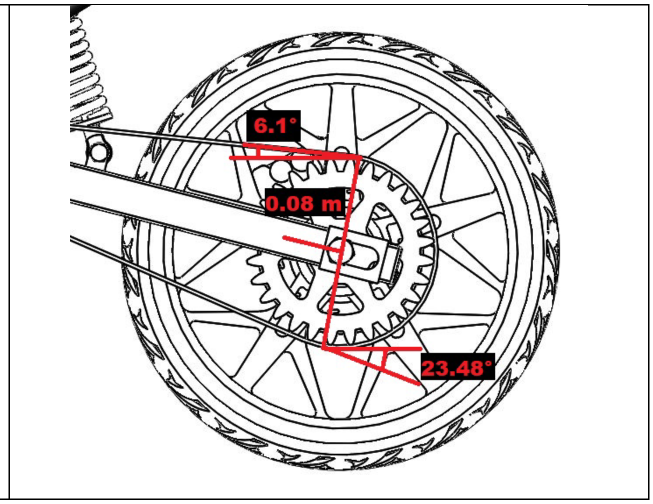


Figure 5. Radius of chain sprocket

$F_{chain\ (lb)} = \frac{P}{Vc}$

P = Power of the motor = 1000 W

T = Torque of the motor = 4 Nm ; V_c = Velocity of chain

N_m = Motor rpm

ω_m = Angular velocity of motor $= \frac{\text{Power (P)}}{\text{Torque (T)}} = \frac{1000}{4} = 250$ rad/ sec

Again, $\omega_m = \frac{2\pi \text{ x Nm}}{60}$

$\Rightarrow N_m = 2387.324$ rpm

$\therefore N_{rear\ wheel} = N_m \text{ x } \frac{\text{Sprocket Teeth}}{\text{Motor Pinion Teeth}}$

$= 2387.324 \text{ x } \frac{14}{38}$

$= 879.540$ rpm

$\therefore \omega_{rear\ wheel} = \frac{2\pi \text{ x Nrear wheel}}{60} = 92.105$ rad/ sec

$\therefore V_c$ = Velocity of chain $= \frac{\omega \text{ rear wheel}}{\text{Pitch circle radius of sprocket}}$

$= 92.105 \text{ x } 0.08$

$= 7.3684$ m/ s

Therefore, $F_{chain\ (lb)} = \frac{P}{Vc} = \frac{1000}{7.3684} = 135.714$ N

$F_{chain\ (ub)} < F_{chain\ (lb)}$; Let's take $F_{chain\ (ub)} = 100$ N

$\sum F_x = 0;$

$\Rightarrow -T + F_{chain\ (ub)} \cos(23.48°) - F_{chain\ (lb)} \cos(6.1°) + F1 = 0$

$\Rightarrow -1158.824 + 100 \text{ x } \cos(23.48°) - 135.714 \text{ x } \cos(6.1°) + F1 = 0$

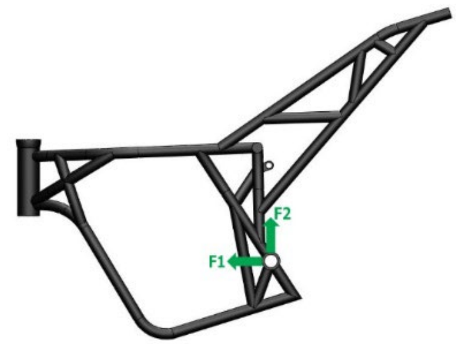
$\Rightarrow F1 = 1202.049$ N

$\sum F_y = 0;$

$\Rightarrow N_r - F_{chain\ (ub)} \sin(23.48°) + F_{chain\ (lb)} \sin(6.1°) – F2 = 0$

$\Rightarrow 833.85 - 100 \text{ x } \sin(23.48°) + 135.714 \text{ x } \sin(6.1°) – F2 = 0$

$\Rightarrow F2 = 808.428$ N

Applied constraints	Applied Force
	

4.4 Forces acting on the bike during maximum braking to the front axle

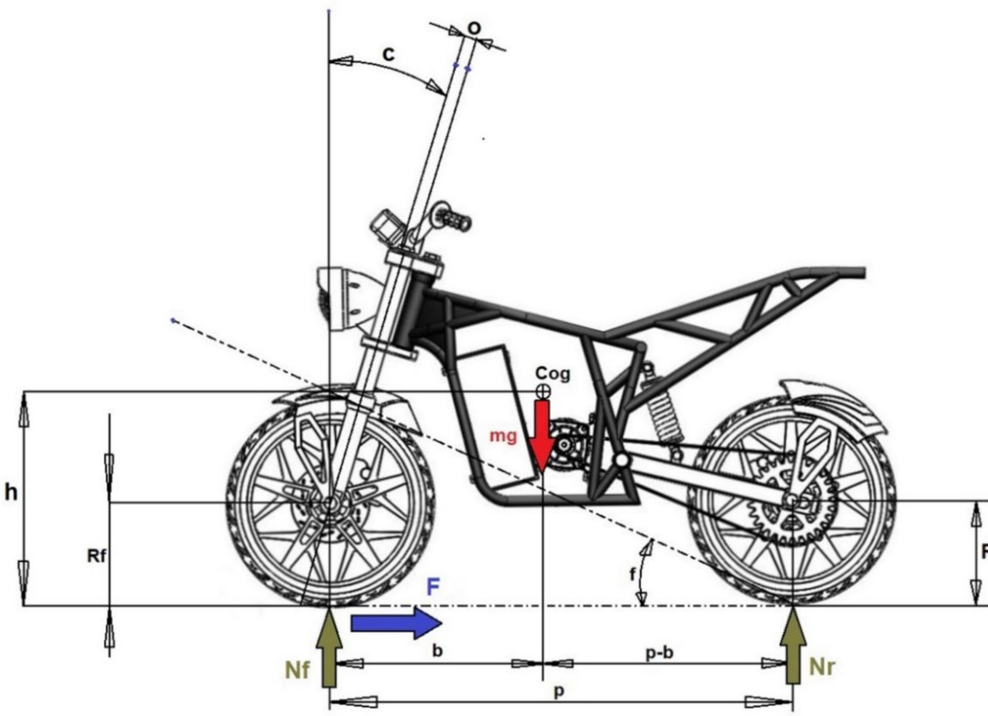


Figure 6. External forces acting on the bike during maximum braking to the front axle

Now, $\Sigma F_y = 0$;

$\therefore mg - N_f - N_r = 0$

Taking moments about CoG,

$$N_f \text{ x } b - N_r \text{ x } (p-b) - F \text{ x } h = 0$$

$$\Rightarrow N_r = \frac{Nf \text{ x } b - F \text{ x } h}{p-b}$$

$$\Rightarrow N_r = \frac{\{(mg-Nr) \text{ x } b\} - F \text{ x } h}{p-b}$$

$$\Rightarrow N_r \text{ x } (p-b) = mg \text{ x } b - Nr \text{ x } b - F \text{ x } h$$

$$\Rightarrow N_r \text{ x } (p-b) + Nr \text{ x } b = mg \text{ x } b - F \text{ x } h$$

$$\Rightarrow N_r \text{ x } p = mg \text{ x } b - F \text{ x } h$$

$$\Rightarrow N_r = \frac{mg \text{ x } b - F \text{ x } h}{p} \text{ (Figure 6)}$$

Since, during maximum braking,

$$N_r = 0$$
$$\Rightarrow \frac{mg \text{ x } b - F \text{ x } h}{p} = 0$$
$$\Rightarrow mg \text{ x } b - F \text{ x } h = 0$$
$$\Rightarrow F = \frac{mg \text{ x } b}{h} = 939.655 \text{ N} \qquad [\because mg = Nf = 85 \text{ x } 9.81 = 833.85 \text{ N}]$$

Contact forces from the floor against the tire are transmitted to the chassis through wheel, brake, front suspension and steering. The points of applications of these forces to the chassis are both steering bearings. The following schematics shows various parameters at the front part of the motorcycle (Figure 7 and 8).

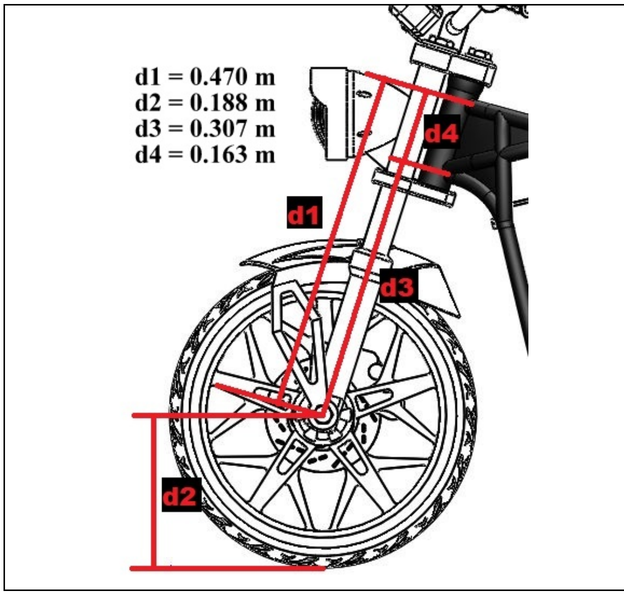


Figure 7. Parameters at the front part of the bike (m)

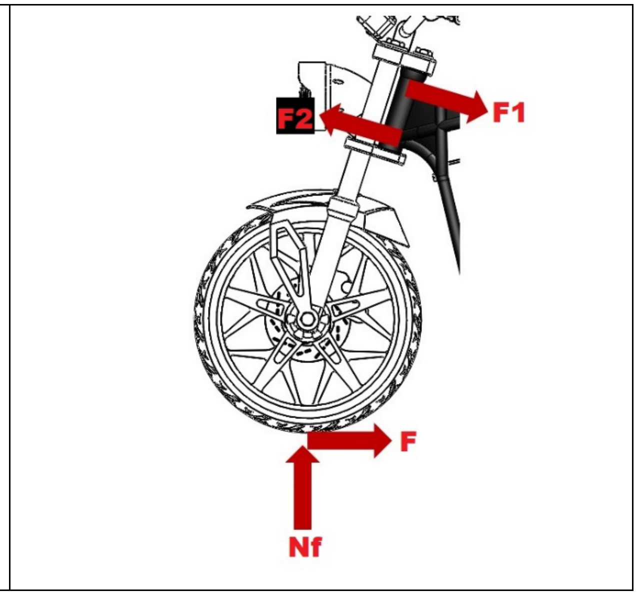


Figure 8. Forces acting during maximum braking to the front axle

Taking moment at the point B to be zero i.e. $\Sigma M_B = 0$;

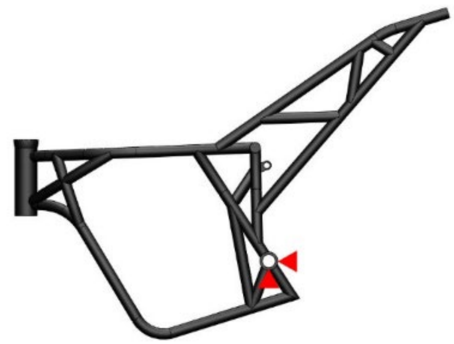
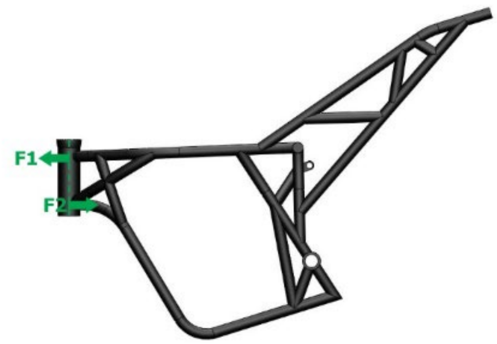
$$+ \quad F \text{ x } d2 + F2 \text{ x } d3 - F1 \text{ x } d1 = 0$$
$$\Rightarrow 939.655 \text{ x } 0.188 + F2 \text{ x } 0.307 - F1 \text{ x } 0.470 = 0$$
$$\Rightarrow 176.655 + F2 \text{ x } 0.307 - F1 \text{ x } 0.470 = 0 \qquad \text{[eqn. 1]}$$

Taking moment at the point C to be zero i.e. $\Sigma M_C = 0$;

$$+ \quad F2 \text{ x } d4 + N_f \text{ x } \sin 17° \text{ x } d1 - F\,(d1 \cos 17° + d2) = 0$$
$$\Rightarrow 0.163 \text{ x } F2 + 114.5831 - 599 = 0$$
$$\Rightarrow F2 = 2971.882 \text{ N}$$

Putting the value of F2 in eqn. 1,

$$F1 = 2317.069 \text{ N}$$

Applied constraints	Applied Force
	

5. Finite Element Application

Once external forces in different situations are obtained, they can be applied to the chassis and results can be analyzed with the help of finite element program. A numerical technique for assessing engineering designs is FEM (Finite Element Method). FEM breaks the designed model into many little sections, called elements, that are made up of simple shapes. The goal of this aspect is to break down a big problem into a series of simple problems that must all be answered at the same time.

Meshing is the process of breaking down a model into smaller components. Finite Element Analysis (FEA) is a type of analysis that uses FEM (FEA).

Nodes are the connecting points between elements. The response at any location within an element is interpolated from the nodes' responses. A number of parameters characterize each node in detail. We used ANSYS as the finite element program in our thesis project.

The equations regulating the behavior of each element are formulated using ANSYS simulation, which takes into account their connectivity to other elements. The response is related to known material qualities, constraints, and loads using these equations.

The solver in a stress analysis program finds displacements at each node, then calculates strains and finally stresses. Displacements, reaction forces, and stresses are calculated in static studies.

Finite element programs have different steps as a process to obtain the final result:
- Firstly, it is needed to upload the geometry that will be analyzed in ANSYS.
- Secondly, it is necessary to perform the meshing. Meshing is done in two sub steps. The first one involves making a general mesh and then getting its results, second meshing is performed emphasizing on the parts that are more important. Thus, we can obtain more accurate results at the critical locations of the designed chassis.
- After meshing, the boundary conditions are to be described (which are the places where displacement doesn't exist or in other words, constraints). Then external conditions such as forces or moments are to be defined.
- Finally, the system is to be solved and then analysis of each result obtained is done. In our thesis project, we have calculated displacements, strains, stresses and factor of safety of the chassis. Materials will fail at the locations where stress exceeds the pre-defined Von Mises Stress. Basing on the results, topology optimization of the chassis is carried out. Thus, we could end up with the design having the most efficient mechanical features and economic viability.

5.1 Maximum Acceleration

The simulations results are shown below in figure 9 and figure 10:

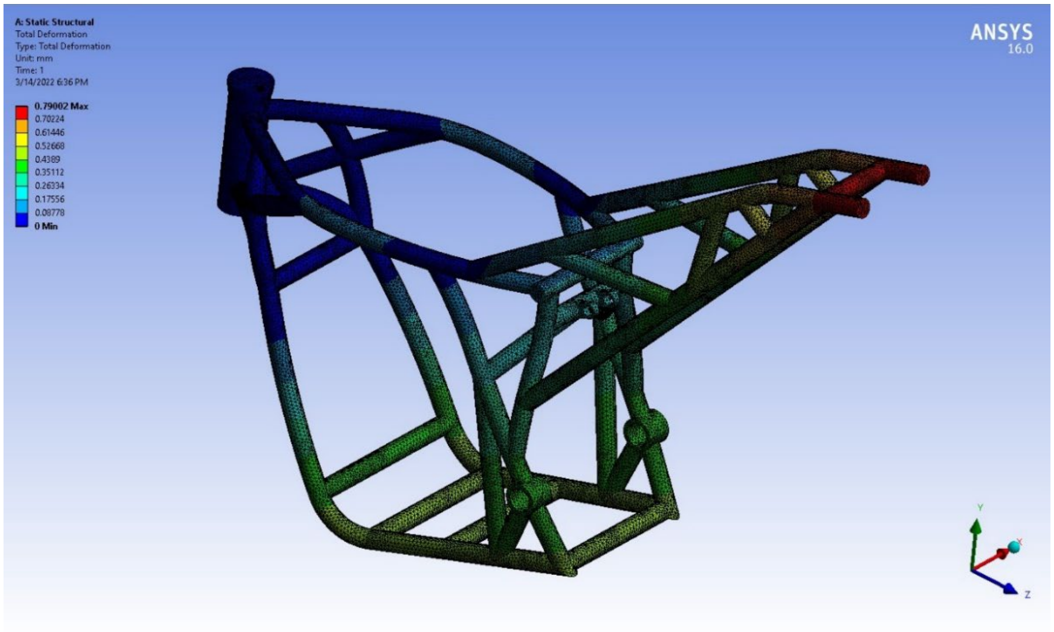


Figure 9. Deformation of the chassis (mm)

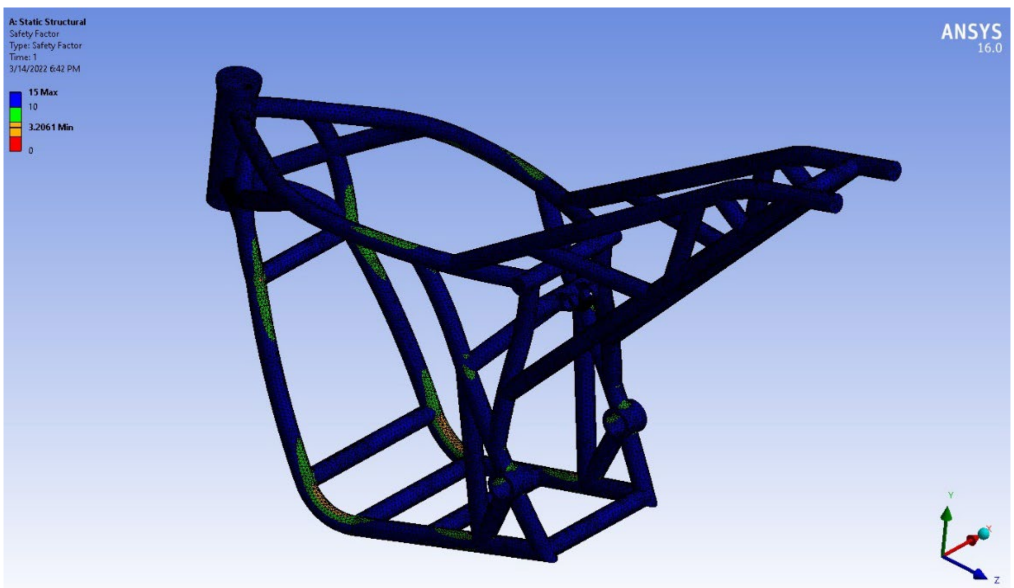


Figure 10. Factor of safety of the chassis

Maximum deformation of the chassis is 0.79002 mm. Minimum factor of safety is 3.2061. Factor of safety is well above unity at all locations of the chassis and so the design can be considered safe and perfect during maximum acceleration.

5.2 Maximum Braking to the Front Axle

The simulations results are shown below in figure 11 and 12:

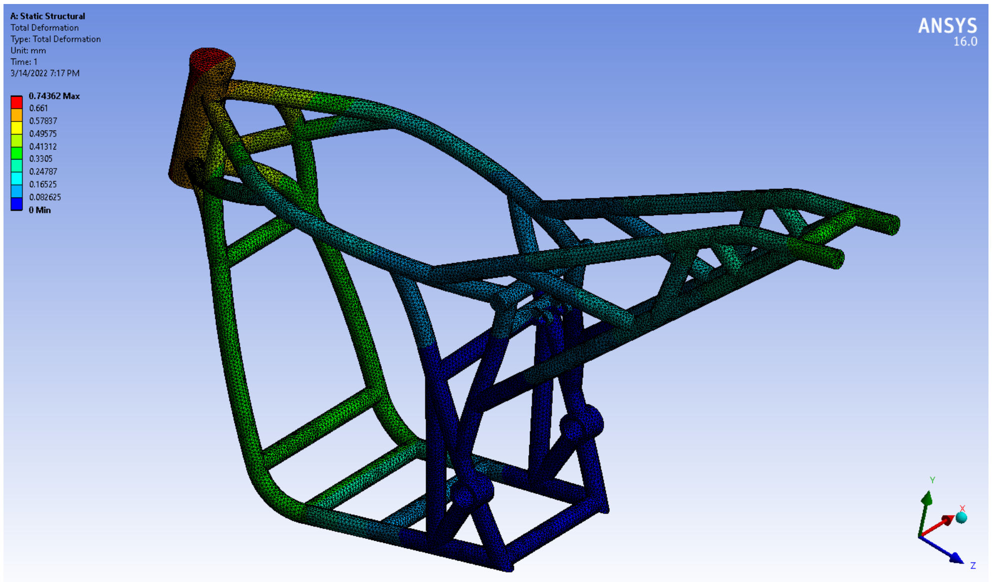


Figure 11. Deformation of the chassis (mm)

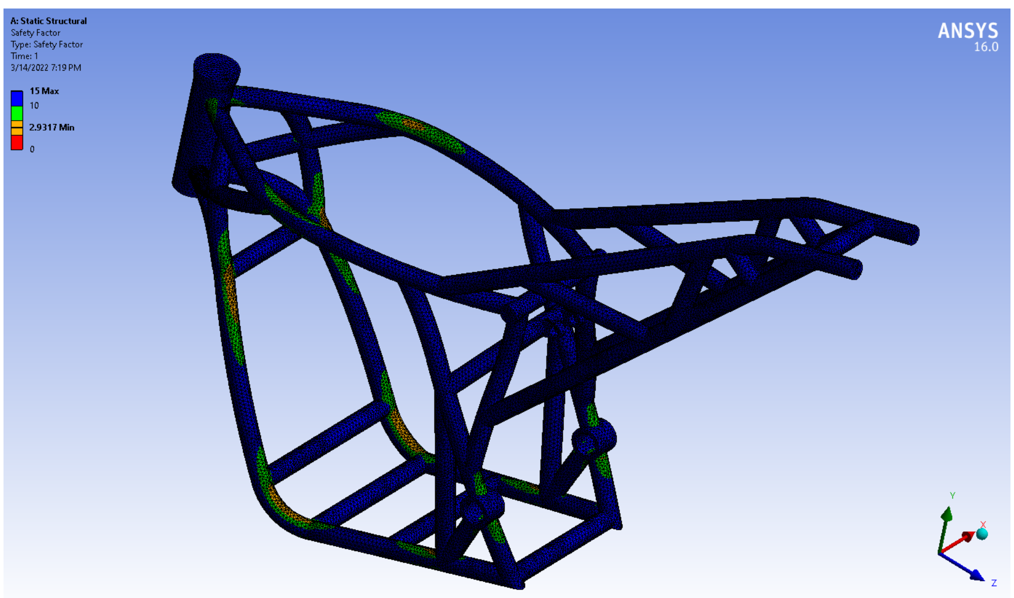


Figure 12. Factor of safety of the chassis

Minimum factor of safety is 2.9317. Factor of safety is well above unity at all locations of the chassis and so the design can be considered safe and perfect during maximum braking to the front axle.

6. Conclusion

The number of automobiles on the roads throughout the globe is increasing at a staggering rate year by year, but the dependence on oil-based fuel grows almost unchecked. Due to this, electric vehicles come into the picture as an alternative. Need for an affordable and efficient mode of transport created a growing demand for electric motorcycles. This paper is taken as an opportunity, rather a challenge to design and develop the best in class electric motorcycle for the quotidian commute. One of the motivations of this paper was to make the chassis of the motorcycle more secure and more reliable so that it can negotiate all the driving conditions in the best possible manner. Much emphasis was put on making the motorcycle chassis as strong as possible to withstand crash and fatigue.

Dynamic features are important to predict the future behavior and so modal analysis was performed on the chassis. It's vitally important to know the external forces as best as possible in order to calculate the internal forces acting on the chassis during maximum acceleration and maximum braking. Deformation and factor of safety of the chassis were determined taking all these forces into consideration.

It's highly desired that the motorcycle's overall design and construction will increase its road performances and meet customer needs if made commercially available. All-in-all, this electric motorcycle can be an aspiring solution to a rather bigger problem than just being a day to day commuter. It can be a step towards an eco-friendly and sustainable mode of transportation.

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Biographies

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Brigadier General Md. Humayun Kabir Bhuiyan, psc is a Senior Instructor and Dean of the Faculty of Mechanical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh. He earned B.Sc. and M.Sc. in Mechanical Engineering from Bangladesh University of Engineering and Technology, Bangladesh, and undergoing PhD in Mechanical Engineering from Military Institute of Science and Technology. Brig Gen Humayun has served in various EME units of Bangladesh Army in various appointments. He has already published many referred journal papers, conference papers and book chapters. His research activities include the area of Operations Research & Management, Military Hovercraft, Subsonic Wind Tunnel, Sustainable Product Design, Maintenance Engineering, Small Arms and Military Optical equipment and Renewable Energy. He has an affiliation with IEB (Bangladesh).

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