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Design and Fabrication of Low-Cost Portable Electric Scooters for Last Mile Connectivity

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Abstract

In metropolitan cities every day, thousands of people commute from one place to another using uncomfortable and polluting means of transport. Literature survey shows there are many varieties of E-scooters available in the market that are either bulky, nonmodular or expensive. Hence the objective is to fabricate a low-cost portable E-scooter that overcomes problems like pollution, range, portability and maneuverability. To fulfil these objectives, project work is initially undertaken with Fine Element Analysis (FEA) of Frame design to withstand all loading conditions. To reduce the cost of fabrication, the design for strength concept is incorporated with the assistance of machine design, vehicle dynamics and electric power train calculations. The present model is 1.27m in height and 0.657m in width considering the anthropometric profile for comfort requirements. The final model consists of many parts mainly, the Direct Current (DC) motor, controller unit, Li-ion battery pack and others. After the fabrication and electric work, the model is tested for manoeuvrability, stability and other ergonomic requirements. It is observed that models can sustain a 120Kg load for a 9km range on fully charged battery condition. Finally, the project satisfies 90% of the design calculations which include, braking distance, acceleration, top speed and gross weight. It is concluded that using design for strength concept, FEA and ergonomic consideration, it is quite possible to fabricate an E-scooter at 50% total cost of the market price.

Keywords: *Battery Pack, DC Motor, FEA, Frame, Stability*

1.0 Introduction

Year by year, the world population and working people's expectations are growing. Travelling and communication have increased at a rapid rate. Due to the advent of new technology, people have many options and thus facilities. But this is restricted to developed countries, due to a better economy. The richer countries therefore follow a highly mechanised life. But in the case of most developing countries, means of travel still need improvement as the cost of living is unaffordable to poor families. Most of the commuters depend on last-mile connectivity and they are not happy with their current means of travelling. Fuel charges are increasing rapidly. Transportation that makes use of the combustion of fossil fuels, liberates lots of harmful exhausts, especially mining vehicles due to the high power requirements to lift and carry mines. Hence, there is a need for a facility that consumes no fuel and helps us to reach our destination at the earliest. The advent of electric scooters has greatly enhanced last-mile connectivity. Literature surveys have shown that there are many varieties of E-scooters available in the market.

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Table 1. Description of E-scooters available in market[6]

S.N	Model	Type of Battery	Load Capacity, Kg	Range, Km	Total weight of the scooter, Kg	Unit price (Rs)
1	MI Scooter	Lithium Ion, 42V. DC,12800mAh/474 Wh	100	30	12	35000
2	Swagtron SG-1	24V,3800mAh Li-ion	113	24	8	35900
3	Razor E prime	36V, Li-ion	80	24	9.8	25000
4	Ecoreco Electric Scooter	Lithium- ferrophosphate battery	100	30	15	48000
5	Zoom Stryder	280 Wh battery pack consists of LG 18650 cells	110	30	11	57000

Electric scooters powered by nickel metal hydride batteries provide a 100km range between recharges[1,2]. One more paper suggested the use of Brushless DC motors as the propulsion method[3]. But the disadvantage of such E-bikes is, they consume more power. A study on portable E-scooters with 2, 3 and 4 wheels respectively was carried out[4], where a lithium polymer battery was used. The author concluded with some key observations. As the number of wheels increases, maximum drive velocity decreases and the cost of fabrication increases. Also, the front drive mechanism with one steering shaft was proposed as the best design among the varieties of scooters. One more paper suggested the use of an E-scooter with a DC Motor and a body built with mild steel[5]. A pragmatic study revealed that the vehicle is very heavy to carry and the speed range is minimal as the ratio of body size to wheel is not appropriate.

After a vigorous market survey, a few important, futuristic and common R-scooters were found and are shown in Table 1. To overcome the deficiency that was observed in the work carried out by the previous authors, the present work was proposed and the main highlights are as below. The work began with preparing a well-structured methodology, followed by a finite element analysis of the critical part of the scooter. Then selection of materials, design concepts and further calculations involved in the detailed parametric studies were carried out. Fabrication of the E-scooter followed by electric parts assembly was carried out. Finally, the E-scooter was tested and the critical observations were recorded.

2.0 Methodology

A well-structured research methodology was followed, considering all the essential design parameters and ergonomics. The chronicle order of the methodology is as below.

1. Thorough market research, keeping in mind the benchmark performance requirements was carried out on the design and fabrication of portable electric scooters.
2. Finite Element Analysis of critical parts of the scooter was carried out to make best use of materials.
3. A parametric study followed by fabrication of an E-scooter was conceded with electric parts assembly.
4. Finally, the model was tested for stability, range and manoeuvrability and the key observations were recorded.
5. A conclusion was drawn highlighting the significant points.

3.0 Experimental Details

FEA of the critical mechanical part of the scooter was carried out. The part selected for numerical analysis was the frame of the E-scooter and it is as shown in Figure 1.

The final selection of the shape of the frame pipe was done based on the literature survey, which reveals circular cross section is better than a rectangular one. A mild steel pipe with a 22.22mm outer diameter and pipe thickness of 1.6mm was selected. This design parameter was decided based on the highest section modulus of circular pipe available in the market. E-scooter is made up of an assembly of mechanical and electrical parts. Experimental work began with the FEA of important parts and then followed by components fabrication, selection and final assembly.

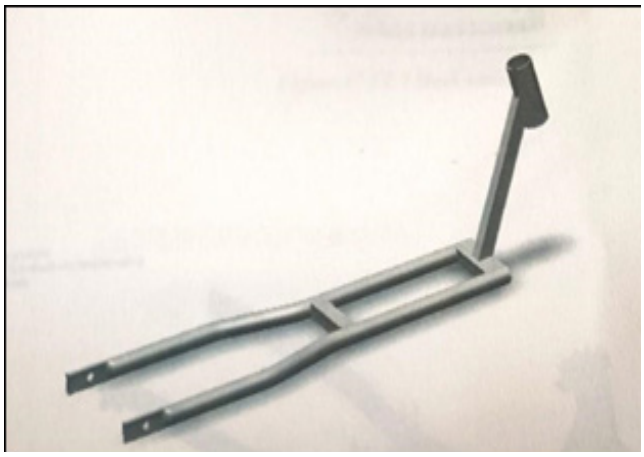


Figure 1. Computer-aided drawing of the frame of the E-Scooter.

Using CAD software, a model of a frame with a vertical pipe and steering holder is created. The frame is analysed, for static strength of the material by constraining all degrees of freedom at the extreme ends as shown in Figure 2. A triangular element of element length 4.5mm and solid mesh type with fine mesh density was selected. Working load in Newton was applied, considering average weight (90Kgs), at the centre of the frame as shown in the figure. The solution was obtained as the maximum displacement of the frame was well below the critical value of 12% elongation[7]. The red colour shows the maximum displacement and the blue colour as the minimum displacement. Other colours are the displacement in between. The figure gives the maximum static displacement of 5e-0.001 mm. Von Mises stress is calculated and the stress distribution is shown in Figure 3.

Red colour shows the maximum static stress and blue color as the minimum static stress. Other colours are the static stress in between. The maximum stress induced is 0.143GPa, which is far below the yield strength of the material of 0.210GPa-0.351GPa[7]. Hence design is safe and thus same frame is selected and fabricated. To promote the design for strength concept, the central part of the frame is made hollow as no load is carried by the E-scooper at that particular place of the scooter. Based on the market survey, a wheel diameter of 180mm, and rubber tyres

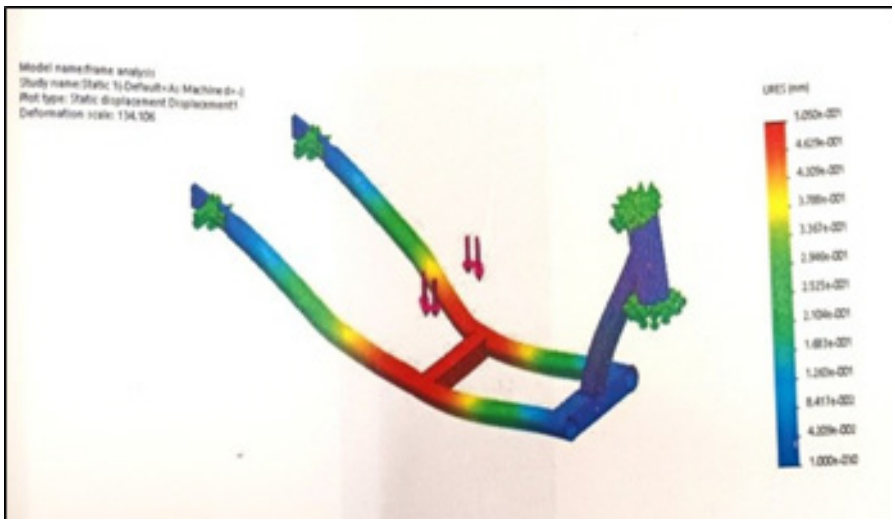


Figure 2. Finite element analysis output in terms of displacement.

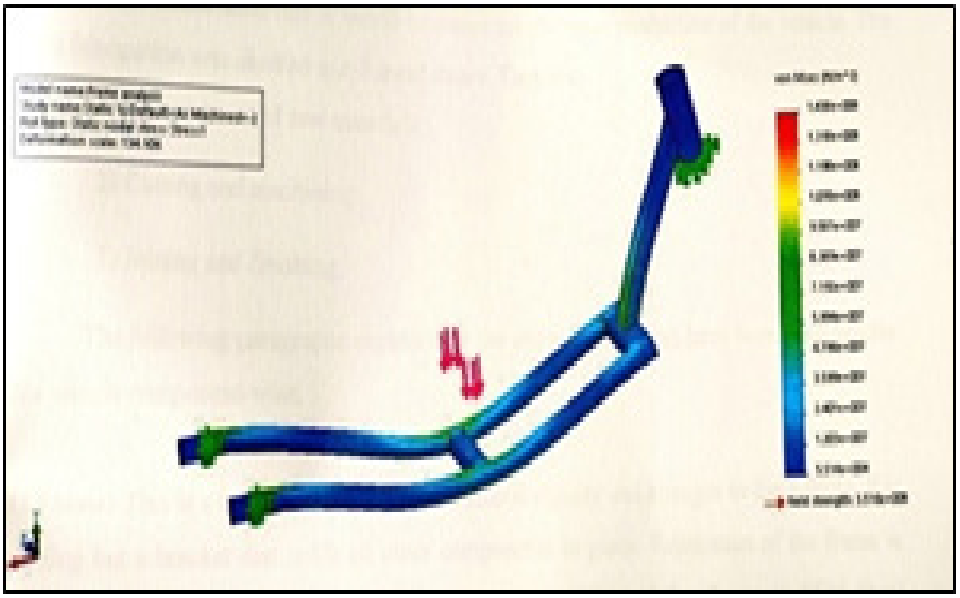


Figure 3. Finite element analysis output in term of stress distribution.

with air-filled tubes were selected. Further, the tyre with a section width of 48mm and rim size of 110mm is selected. The torque required at the wheels is calculated as 10.8Nm, based on the total tactile efforts. The motor selected to drive the vehicle is a 24, DC motor, as it is less costly and easy to maintain. Chain–sprocket assembly is selected, as it is economical and functions better under shock loads. A shaft made up of EN24 steel with a 10mm diameter is selected, based on design calculations.

Electrical subsystems consist of a motor controller, throttle, brake sensor, power switch ON/OFF, Battery pack, charger and wiring harness, etc. The motor controller is a permanent magnet DC motor controller with a rated voltage of 24VDC and a maximum current of 30A. An electronic twist-type throttle is used as it is a rotary variable potentiometer that is connected to a motor controller through a Molex automotive connector. The brake lever and sensor are used to detect the depression of the brake lever and to send the signals to the motor controller.

Battery pack design consists of battery cells that are stacked vertically so that the vehicle can be made more compact. 28 cells are stacked in 7 layers and each layer is physically separated by an insulating and fire resistant material known as glass-epoxy sheet. The thickness of the sheet is 0.5mm each. These are further wrapped separately in epoxy paper. Lithium Ion 18650 cells were selected as these are light in weight and economical. The battery charger used is 24V, nominal current output -5A, voltage input-220V AC. And current input required is 15A. Battery voltage Indicator: It is a digital voltage indicator which displays the voltage of the battery pack, capable of showing the range of 4V-30V. The voltage indicator does not need an extra power supply.

Ergonomics and vehicle dynamics: The primary goal of the design of the E-scooter is to fabricate the vehicle so that all classes of people can use it easily. Anthropometry, for example, gives the range of men's height as 1.5 m to 1.85m. Platform height and width are decided so that, in case the power is not sufficient, a person can use his legs to push and move ahead. The average chest height of Indians is considered while selecting the total handle height from the ground. Vehicle dynamics broadly includes the study of forces acting on the vehicle including longitudinal and lateral dynamics. In this study rider and vehicle are taken as one entity. External forces are gravitational force that pulls the rider and bike towards the ground. Internal forces include those between the bike and the rider. For example, pedalling force, torque applied between the steering mechanism and rear frame, and friction in the drive chain and brakes. A band brake consists of a flexible band of leather enveloped with steel lining with friction material designed to stop the rotating drum. The design of a brake involves many calculations.

A few important were as below;

T1 is the tension of the band on the tight side and T2 is tension on the slack side of the band. Take μ, coefficient of friction as 0.25 and θ = 230 Degrees as the angle of lap.

$$\frac{T1}{T2} = e^{\mu\theta} \quad (1)$$

Using equation (1), T2 is calculated.

$$r = \frac{M_t}{(T1 - T2)} \quad (2)$$

Radius of the drum is calculated by using equation (2). Where Mt is the calculated torque and the value of the radius of the drum is 40mm. The total width of the band considering 4 rivets is 13mm.

4.0 Results and Discussion

After the fabrication and selection of mechanical and electrical components, the assembly of the parts is done. The final model is shown in Figure 4. E-scooter tests have been carried out to check the performance and to determine the selection parameters.

The final vehicle gross weight in the absence of the rider is measured using the weighing machine. And weight obtained is 11.5Kg. hinge and sleeve mechanism is tested for easiness and reliability for 50 cycles. Also, it is ensured that the vehicle can be easily foldable and unfoldable. Weight carrying capability test is done and found that this scooter can withstand up to 120Kg load. The scooter is driven on the concrete and tar roads to check its stability and measurability. The following observations as shown

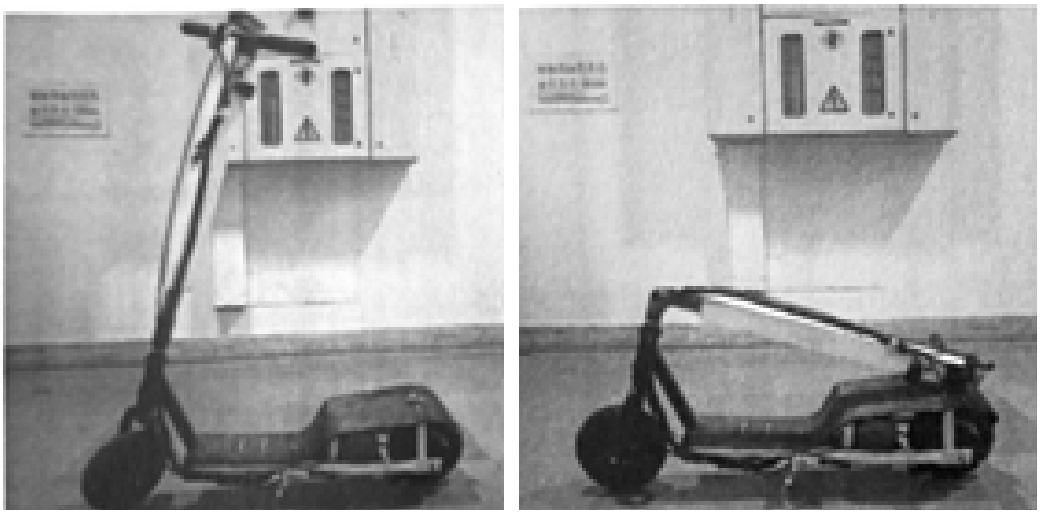


Figure 4. Fabricated pictures of the E-scooter in standing and folded form.

Table 2. Results of performance of E-scooter

Selection Parameters	Calculated Values	Obtained Values
Vehicle gross weight (Kg)	11.0	11.5
Top speed (Kmph)	16.2	15
Acceleration ( ) at 100 kg load	0.49	0.45
Range in Km between 1 full charge	10	9
Braking distance in meter	1.47	1.5
Load carrying capacity in Kg	100	120

in Table 2, were recorded after many trials. The cost of the vehicle would be approximately Rs. 13,750.

5.0 Conclusion

Transportation that makes use of combustion of fossil fuels, liberates lots of harmful exhausts. Especially mining vehicles due to high power requirements to lift and carry mines. A portable and handy electric scooter was successfully designed and fabricated to enable short-distance commutes and last-mile connectivity. This concept can be extended to design and fabricate mines carrying vehicles. After considering the design for strength concept, potential market survey and FEA results, it is quite possible to fabricate E-scooter at optimum cost and to meet the calculated values of selection parameters. The final model can carry a 120Kpay loaded with a speed range of 12 -15Kmp. The cost incurred in fabricating this model is approximately Rs. 13,750.

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