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Design of Six Seater Electrical Vehicle (Golf Cart)

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Abstract: In this paper, six-seater Golf Cart has been designed and developed in The IFTM university at 28.81°N, 78.64°E. All components of the Golf cart like the frame of the vehicle, transmission system, brakes, batteries, motor, tyres, and motor controller have been designed and fabricated. The Golf Cart can sustain a maximum load of 15 KN on the bumpy and terrain road at a maximum speed of 48 Km/hr. The batteries of the Golf Cart are placed below the seats to minimize the car space and over-turning moments on terrain roads. The modeling of various components of the Golf cart has been done in CATEA software. The maximum torque obtained at the 800, 1360 and 1500 RPM are the 2.1 Nm in 0.35 s. The six-seater Golf Cart works very efficiently and smoothly on the smooth, bumpy, and terrain road. It is very efficient to take the load of six passengers in a rural area. It did not produce noise and air pollution due to use of DC motor.

Keywords: Induction motor; Batteries; Brakes; Vehicle; Design; Frication.

1. Introduction

In recent time, pollution, global warming, and acid rain are the major environmental problems[1)]. These all problems have been generated due to the use of Internal Combustion Engines (ICE) in the automobile sector. The ICE generated the power due to the combustion of fossil fuels like petrol, diesel, and gaseous fuel. These fuels generate harmful gases like CO_2, CO, SO_2, smoke, and particulate matter[2)]. These gases are the major cause of the above said environmental problem and a number of health issues in the human being[3)]. So, the government decided to replace the ICE from the automobile sector by importing electrical motor and batteries.

The battery-operated vehicle generated the concept of an Electric Vehicle (EV). The most important benefit of electric vehicles is that these vehicles provide high torque even at low speeds[4)]. In urban areas and busy market, vehicle running at low speed requires high torque so the battery-operated electric vehicle is the best option[5)]. The battery-operated electric vehicle does not generate any noise. So, battery-operated electric vehicles will be the permanent solution of air and noise pollution which is a big problems in developed and developing countries.

The electric vehicle is a combination of mechanical design and a complex electric control unit. The battery is the main source of energy for the whole vehicle which runs the motor, clutches, brakes, air conditioners, and all other components of the vehicle. Figure 1 and Figure 2 show the block diagram of the energy system and its management for operating all components of the vehicle. The controller controls the power supply from DC to AC by the inverter to maintain the optimum speed at the particular load in the Gulf cart. The air-conditioning requires the AC supply from the batteries due to that an inverter being used between the batteries and the air-conditioning unit. The electric vehicle mileage is the big problem[6)].

The brake vacuum pump and 12 V lighting have required a separate battery for the 12 V power supply as shown in Figure 1. For charging the battery a DC/DC converter has been used which converts the 12 V DC power supply for charging the battery.

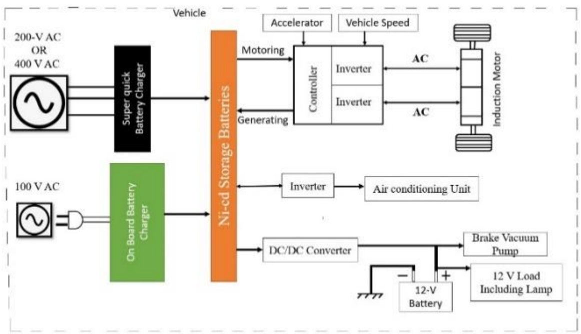

Figure 1: Energy management in electric vehicle[7)].

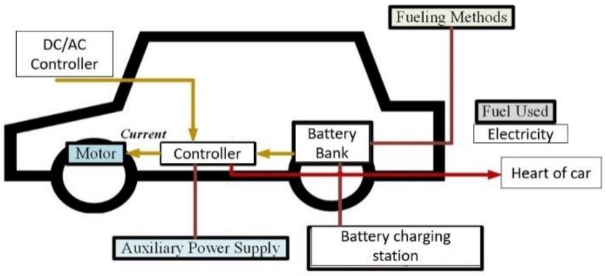

Figure 2: Location of energy-supplying components in the car

Figure 2 shows the location of the various components used in the gulf cart. The components located in the Golf Cart at various locations depend on the balancing of the vehicle. The battery bank is fixed on the rear wheel side and the motor is located on the front wheel. The controller is fixed in between the motor and the battery bank. The controller controls the power supply to the auxiliary components of the vehicle like clutch, brakes, lighting, steering, etc.

The above literature shows that electric vehicles replace fossil fuel operated vehicles since electric vehicles are non pollutating in nature and not produce any harmfull environment effect. For busy and bumpy road, electric vehicle operate at low speed but at low speed DC motor produce the enough torque and controlling to the EV[7]. The AC motor has higher performance but low torque compared to DC motors. The selection and positioning of the batteries in the electric vehicle done very wisely since increasing the number of batteries enhance the load and cost of vehicles.

2. Components of Golf Cart

2.1 Motor

The DC and AC both types of motors can be used in electric vehicles but AC motors have several advantages over DC motors. The AC motor has higher efficiency, lower maintenance cost, high power energy density, and an efficient regenerative braking system. Figure 3 shows the AC motor classification used in electric vehicles as per the load and torque.

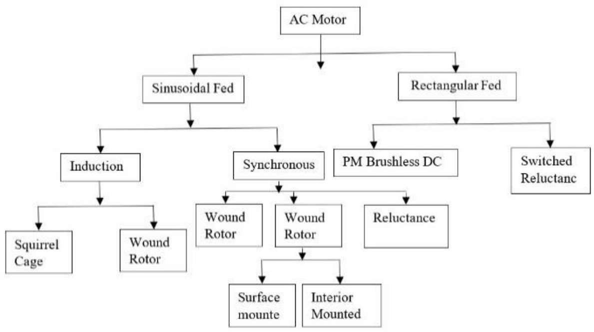

Figure 3: AC motor classification[7]

In rectangular-fed and sinusoidal-fed permanent magnet brushless DC motors, squirrel cages and switched reluctance are very much used in electric vehicles[8].

As per the easy availability and effectiveness 4 kW DC motor, 3000 rpm and 14 Nm has been selected in Golf Cart. For speed reduction as per the load transaxle has been used in Golf Cart[9]. The transaxle is the integrated assembly of transmission, differential and the ancillary system. In golf card, the transaxle of the 10.45 speed reduction has been used. Figure 4 represents the motor transaxle assembly in the golf cart.

Figure 4: Assembly of the motor and transaxle

2.2 Batteries

The selection of battery type and the number of batteries depends on the total load on the vehicle. The selection of the type of battery is done based on four important parameters like energy density, power density, life cycle, and the cost per kWh. The life cycle of the battery should not be less than the vehicle's life since the change in batteries increases the cost for the vehicle owner. The various types of batteries have been used in electric vehicles. The advantages, disadvantages and types of batteries used in electric vehicle are given below.

2.2.1 Lead Acid Batteries

The lead acid batteries generate low specific energy, typically lesser than 20 to 40 Wh/kg[10]. For the range of 200 Km around 150 Kg lithium-ion batteries are required as compared to 500 Kg lead acid batteries[11]. Although, due to the low cost of lead acid batteries (100 USD/kWh) [12], these are preferred for short-range vehicles.

2.2.2 Nickel Hydride batteries (Ni-MH)

This type of battery is mostly used in hybrid vehicles since their energy density is in between the lead acid batteries and the Lio-ion batteries. These batteries are inefficient for alone use in Battery Electric vehicles (BEV) [13].

2.2.3 Lithium Ion Batteries

Lithium-Ion batteries will be the future of the battery-operated vehicle. These batteries have very high electrochemical potential and low equivalent mass. It has also high efficiency and long life. Although, these batteries are costly having USD 700/kWh[14]. The main problem with Li-Ion batteries is the availability of the material. There is a large variety of Li-Ion batteries available presented in Table 1.

Table 1: Different types of Lithium-Ion batteries[13)]

Technology	Advantages	Disadvantages
Lithium Cobalt Oxide ($LiCoO_2$)	Power and Energy density	Safety, cost
Nickel Cobalt and Aluminium (NCA)	Power and energy density, Cycle life	Safety
Nickel Manganese Cobalt (NCA)	Power and Energy density, Cycle and calendar life	Safety
Lithium Polymer ($LiMnO_4$)	Power Density	Cycle Life
Lithium-Ion Phosphate ($LiFeO_4$)	Safety	Energy density, Cycle life

For operating the batteries in safe mode battery management system work in the vehicle. The battery management system plays two important roles in the vehicle. The First role is to check the proper charging, discharge, safely deliver of power, and battery life. The second role is to operate the batteries in a safe, efficient, and non-damaging mode.

In the golf cart design 6 lead acid batteries of 190 Ah with an 8 V supply have been used. The selection of batteries is done based on the power required, availability, and cost as compared to lithium-ion batteries[15)]. For minimizing the unbalanced force and volume of the golf cart, the location of the batteries has been fixed. The batteries are set below the seats of the golf cart so that the full volume of the golf cart is properly utilized. The golf cart's center of gravity should be near the ground to minimize the overturning moment on the inclined plain. The weight and the size of a single battery is 25 Kg and 259 x 183 x 340 mm respectively. Figure 5 shows the pictorial view of the lead acid batteries used in golf cart.

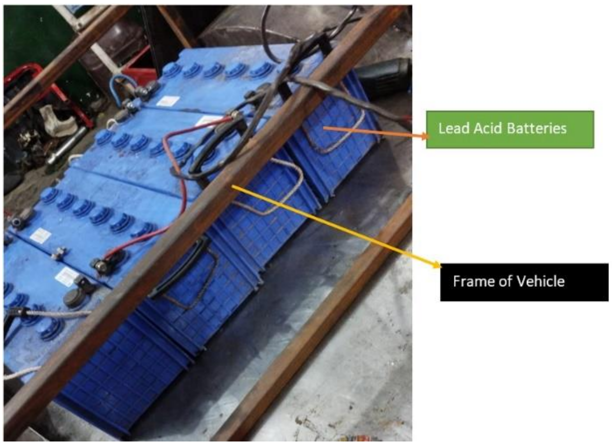

Figure 5: Pictorial view of the lead acid batteries

2.3 Power Electronics

The power electronics exist in between the batteries and the motor. It is composed of the DC/AC inverter which supplies the optimum power to the motor. The control algorithms work at the highest efficiency, and the maximum efficiency of the power electronics is 95 to 98%.

2.4 Charging

The vehicle has been charged by plugging with the switch. This method is light, compact and efficient have bidirectional in nature. The line cables have the high voltage and high current supply but it is inbuilt in the charger that if the charger is not properly connected then the power supply stopped . The different level of charging is provided in the vehicle depends on the charging time. Table 2 represents the different levels of charging.

Table 2 Different level of charging

Level	Voltage	Current	Time of charging
Level-1	220 VAC	15 to 20 A	5 to 8h
Level-2	220 VAC	40 A	3 to 4 h
Level-3 (Fast Charging)	480VAC	3ϕ circuit with Power (60-150 kW)	10 min

In the fast-charging mode production of sparks and risk of fire hazard is higher than in Level-1 and Level-2 since higher current and voltage are involved in the charging[16)]. Figure 6 shows the charger of the golf cart.

Figure 6: Golf cart charger

2.5 Golf cart motor controller

The motor controller is the very important part of the golf cart drive. It maintain the on/off switch facility of the motor as well as maintain an optimum speed of the drive in long range[17)]. Figure 7 represents the motor controller microprocessor.

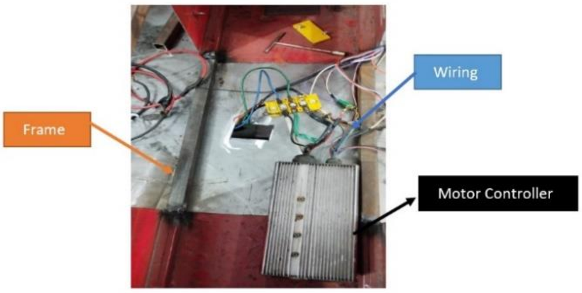

Figure 7: Motor charge controller

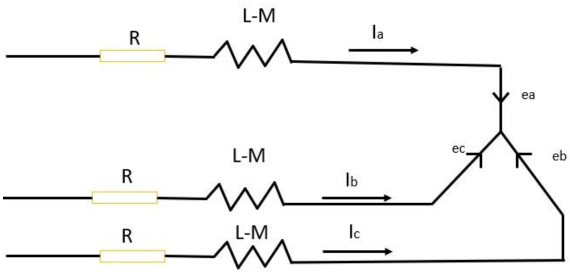

Figure 8: The electric circuit of the controller

Figure 8 represents the equivalent electric circuit of the brushless DC motor. The stator winding has the phase angle of 60° with Y connections. The electromagnetic torque generated by the rotor is given by following equation.

$$T = (e_a i_a + e_b i_b + e_c i_c)/w \qquad (1)$$

Where ia, ib, and ic are the phase winding current of stator and ea, eb and ec are the electromagnetic force of the stator. w represents the frequency of the rotor current.

2.6 Chassis Structure and material selection

The chassis structure of an electric vehicle is designed based on the vehicle's space, rigidity, lightweight and aerodynamic efficiency. The chassis designed is briefly explained in the[18)]. The vehicle size has been reduced by using the aluminium and composites in place of steel[19)]. On the other hand composites and aluminium increase the cost of the vehicle.

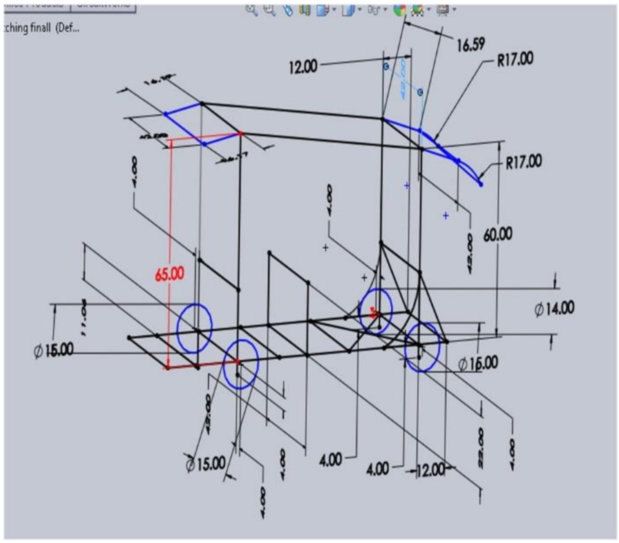

Figure 9: CATIA modelling of the chassis of the Golf cart

Figure 9 shows the CATIA geometry modeling of the chassis structure. It has included the dimensions of the whole frame of the chassis. Mainly the two different types of frame shapes have been used in the chassis. One is the round bar and second is the rectangular bar. The AISI 4130 steel has been selected for the frame of the Golf cart. Table 3 shows the properties of the AISI 4130 steel.

Table 3: AISI 4130 steel composition

Element	**Percentage**
Carbon	0.28-0.33
Chromium	0.8-1.1
Manganese	0.7-0.9
Molybdenum	0.15-0.25
Phosphorus	0.035 max
Silicon	0.15-0.35
Sulphur	0.04 %

Table 4: AISI 4130 mechanical properties

Mechanical Property	**Magnitude**
Density	7.7-8.03
Poisson's ratio	0.27-0.3
Elastic Modulus	190-210
Tensile strength	560.5
Yield strength	360.6
Elongation	28.2
Reduction in area	55.6
Hardness	156
Impact strength	61.7

Figure 10 shows the solid works drawing of the frame of the golf cart. On the front, mid and rear side the 6 seats are fitted and batteries are placed below the seats for proper utilization of the frame space. Figure 11 shows the pictorial view of the frame of the Golf cart in the construction site. In most of the part of the frame the rectangular bar has been used in the Golf cart for maintain the strength and rigidity of the bar. The length width and height of the frame has been selected to be 108 x 42 x 72 inch. The Figure 9 shows the dimensions of all rectangular bars.

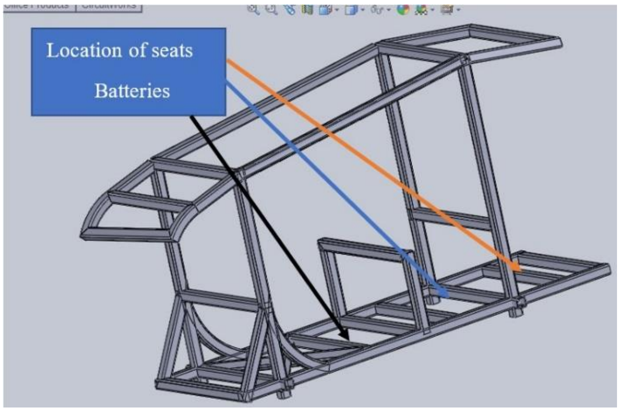

Figure 10: Solid works design of the frame of Golf cart

Figure 11: Pictorial view of the frame of Golf cart

2.7 Steering arrangements

Steering is the very important part of the car since the driver control the whole vehicle with the help of the steering. The shape and size of the steering depends on the number of factors like easy to handle, slip angle of tyre, side slip angle, dimension of the vehicle and tyre size. In Ackerman steering mechanics the following equation has been used for designing the correct steering[20].

$$Cot(\emptyset) - \cot(\theta) = c/b \qquad (2)$$

Where c is the distance between the pivoted points, b is the distance between wheel base, ϕ is the angle turned by outer wheel and θ is the angle turned by the inner wheel. These dimensions are shown in the Figure 12.

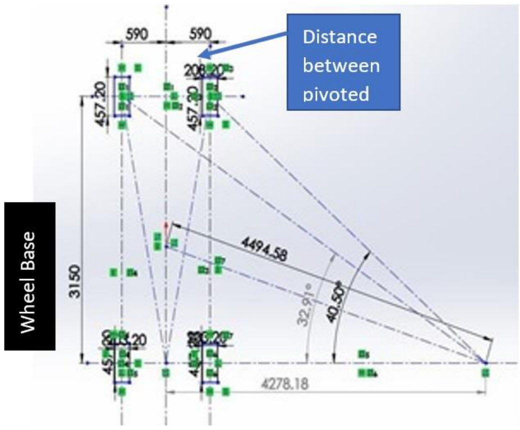

Figure 12: drawing of steering mechanism

In Figure 12 the wheel base, pivoted point distance, inner wheel angle and outer wheel angle has been selected to be 3150 mm, 1180 mm, 32.91° and 40.50°.

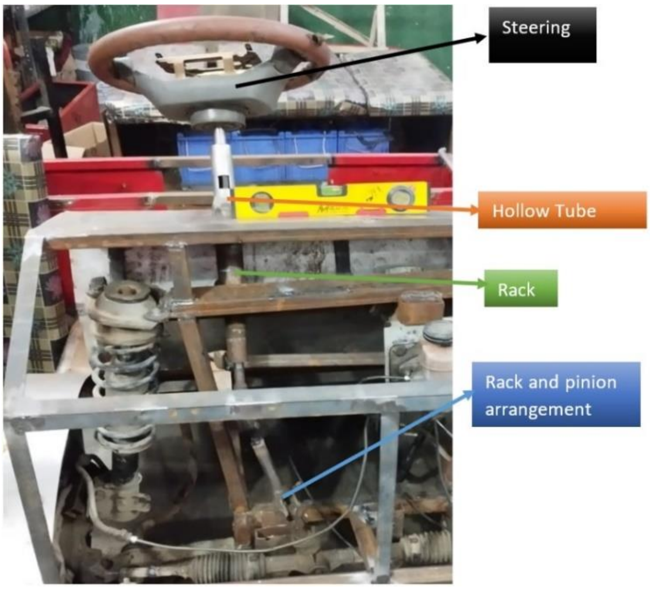

Figure 13: Pictorial view of the steering system in Golf Cart

In Figure 13, a pinion gear is attached to the steering shaft. The turning of the steering wheel turns the pinion gear and moves the rack. The rack and pinion gear are enclosed in a metal tube. A tie rod at each end of the rack connects via the swivel ball joint to the steering arm which finally turns the wheel.

2.8 Suspension system of Golf Cart

The suspension system design in electrical vehicle is very important. It provides the safety against the fatigue failure of various components of vehicle. For suppressing sudden and fluctuating load number of springs and shock absorbers have been used in front and rear side of the vehicle. The development of crack within the components is the main cause of the fatigue failure. The Society of Automotive Engineering (SAE) list the several of the fatigue failure, namely manufacturing defects, heat treatment, poor choice of production techniques and material defects[21].

In the Golf Cart, the independent suspension system has been used. The front and rear wheel suspension systems are separately designed. On the front wheel, the helical coil springs and on the rear wheel leaf springs have been used.

2.8.1 Front suspension system

The double wishbone system has been used in the front suspension of the Golf Cart for safety on the rough and tidy road. The independent wishbone system allows the all four tires to move independently. The suspension system has been designed for maximum load carrying capacity of the 15 KN that consist of the vehicle load, passenger load, luggage weight and safety load against the jerk.

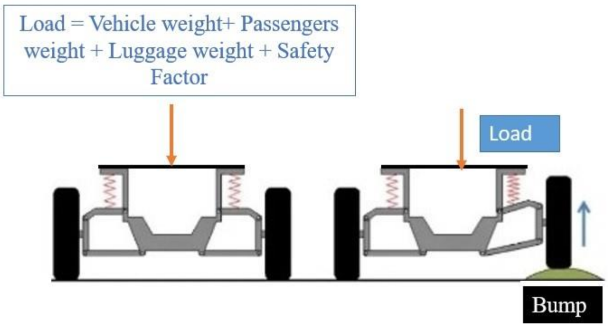

Figure 14: Independent suspension system

Figure 14 shows that the independent suspension system can work autonomously against any bumpy road. In the independent suspension system, the deflection of the wheel is not transferred to other wheels. Figure 15 represents the CATEA drawing of the independent suspension system in front wheels. The all the dimensions in drawing have been represented in mm.

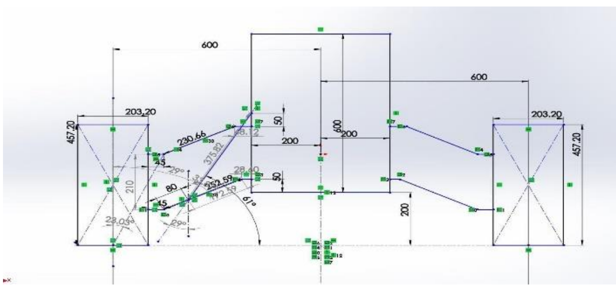

Figure 15: CATEA drawing of independent suspension system

Figure 16: Actual picture of suspension system

Figure 16 represents the actual picture of the suspension system at the time of manufacturing of the Golf Cart. The dimensions of various components have been selected to be as per presented in drawing Figure 15. The measurements of upper wish bone and lower wish bone are 230.66 mm and 252.59 mm. The 4130 steel is selected material for the wishbones.

2.8.1.1 Strut design

The strut design is the important part in the suspension system. The strut consist of the spring and the damper shock absorber system[20]. The strut has been selected from the design data hand book represented in Table 5.

Table 5: Properties of strut material

Code	Length (inch)	Length (mm)	Internal Diameter (inch)	Spring Constant (N/mm)	Spring Travel Ratio (inch)	Load capacity (N)	Weight (Kg)
12002500550S	12	305	2.5	96	6.17	15079	3.05
12002500500S	12	305	2.5	88	6.51	14466	2.75
12002500525S	12	305	2.5	92	6.35	14830	2.89
12002500600S	12	305	2.5	105	6.18	16485	3.10

2.8.2 Rear suspension design

For rear suspension system design, the leaf spring has been selected to suppress the vibration. The leaf springs can sustain the heavy load and effectively work at very bumpy load[22].

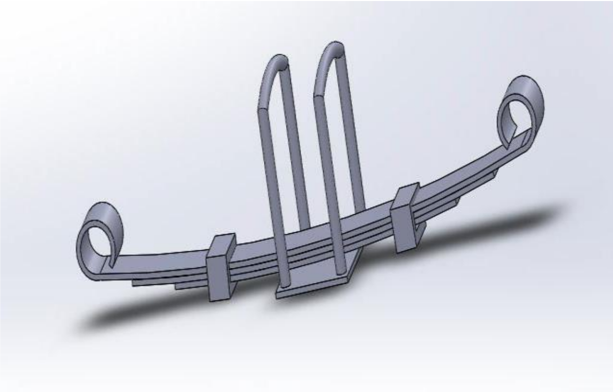

Figure 17: Laminated leaf spring

Figure 17 shows the laminated form of leaf springs. The varying length of leaf springs are fixed and tightened by nut and bolt arrangements. At the vertical loading on rear end of vehicle, the leaf springs work as the cantilever beam. The cantilever beam has the maximum bending moment at the center of the beam so that the short length leaf springs are used at the center part of the beam.

Figure 18 shows the actual picture of leaf springs used in Golf Cart. The figure clearly shows that a plate and the nut are used to fixed the leaf springs collectively. For absorbing the shock load on bumpy road, the chromium steel of AISI 5150 has been selected for the leaf spring material. The chromium steel has excellent mechanical properties, namely young modulus 210 GPa and yield stress of 1520 MPa.

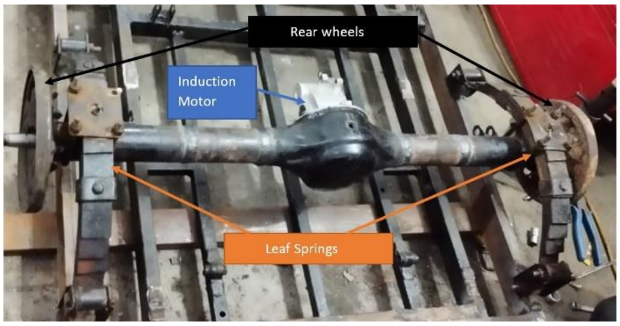

Figure 18: Leaf springs in Golf cart

2.9 Tyres

The selection of tyres in the electric vehicle is done based on the hub size[23]. The Golf cart tyres has been selected based on the tyre pressure at full load and the hub size. The height and width of the golf cart tyre is the 18 inches and 8.5 inches as shown in Figure 19.

Figure 19: Golf Cart tyre

2.10 Brakes designing

Brakes are provided in the vehicle for slowing and stopping the vehicle at the will of the operator. There are number of types of brakes available in market for electrical vehicle but hydraulic disc brakes have been selected for the Golf cart. The disc brakes are chosen over drum since the disk brake has the caliper mechanism that is easy to service at minimum cost. Furthermore, disc brake has very compact space can be fitted in very small space[23]. The hydraulic disc brakes slowing and stopping the vehicle for very smooth manner. The specification of hydraulic brake is given in Table 6[24].

Table 6: Specification of disc brake

S.No	Parameters	value
1	Pedal force	170 N
2	Pedal Ratio	6:1
3	Tie rod diameter	19 mm
4	Caliper diameter	40 mm
5	Brake disc diameter	190 mm
6	Wheel size	18 inches
7	Mass of vehicle	850 Kg

3 Results and discussion

After designing and fabricating the Golf Cart, the Golf Cart has been tested. The experimental test has been done for determing the maximum speed, the charging requirement and mileage. The test has been conducted between the IFTM University and Anand Vihar Delhi on NH-24.

The results shows that the maximum speed gained by the Golf Cart was 48 Km/hr. The total distance between the IFTM university and Delhi is 192 Km. After one time charging, total distance cover by the Golf Cart is 151 Km.

So, two time charging is required for reaching the Delhi.

The maximum torque obtained at the 800, 1360 and 1500 RPM are the 2.1 Nm in 0.35 s.

4. Conclusion

The following outcomes were made in the design and fabrication of the golf cart:

- A lot of market research went into the design of the electric golf cart and desirable results were achieved.
- Finalizing the design of the chassis and trying to innovate with different pipe sizes and shapes gave a unique looking cart with considerable strength and balance.
- An excellent range of mileage of 37 km is obtained for such a heavy vehicle with lead acid batteries.
- The performance of overall vehicle including its speed, braking distance and turning radius, which were achieved under the pre-set assumed values.
- The suspension design was selected carefully to give the best performance at maximum loading conditions.
- The transaxle ratio of 10.45 gives the most optimum output with the coupled motor. The Golf Cart is able to climb fully loaded in grassy/muddy terrain with 20° inclination from horizontal as per design.
- The heavy batteries placed below the seats makes the majority of the weight carried by the cart at low height even after passenger is seated, which gives the entire cart a very low roll center that reduces the risk of cart rolling during uneven terrains.
- In the future, the PV module will be used in the electric vehicle for supplying the power. The main drawback of the solar PV module is its low efficiency at high temperature[25].

Nomenclature

e	Electromotive force
I	Current (A)
b	Distance of wheel base (mm)
c	Distance between pivoted points
θ	Angle turned by inner wheel
ϕ	Angle turned by outer wheel

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