DYNAMICS OF AN ELECTRIC GO KART

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Abstract

Today with the growing population, the number of vehicles is growing drastically. This growth has led to massive increase in air pollution. Around the globe, automobile sector is the major contributor towards air pollution. Go-karting is a growing segment in the automobile sector. In order to control air pollution through this growing segment, this paper aims towards designing of an electric kart which is environment friendly as it causes no pollution. Various subsystems of the vehicle i.e. Chassis, Steering, Brakes & Powertrain were designed and fabricated. The designs were continuously iterated in order to optimize the performance along with adequate driver safety. The electric kart is motor and battery operated. The designs aimed towards a lightweight and highly stable vehicle in order to maximize the power to weight ratio. Reliability, durability, safety & comfort were the key factors which were kept in mind while fabrication of the electric kart.

Keywords: *Electric kart, Subsystems, Performance, Stable, Power to weight ratio.*

1. Introduction:

Go-karting originated in early 1950's in America and instantly became popular, which lead to rapid spreading in other countries. Since then go-karts used 2-stroke & 4-stroke air-cooled engines which are operated on gasoline. Sometimes motor cycle engines are also used as a power unit in go karts. The use of fossil fuels in go-karts not only adds to air pollution but also leads to fast depletion of fossil fuels due to their excessive use and limited stocks. The engines used have bad exhaust systems and are not even fully optimized to decrease the emissions. Some go-kart engines even give out more emissions than a passenger car.

In order to tackle all these issues and keep our environment pollution free and healthy, there is an urgent need to explore alternatives to fossil fuels. Numerous efforts are being put forward to power the vehicles through hydrogen, bio-diesel, ethanol, methanol, CNG, solar power, batteries etc.

In order to explore opportunities with an electric kart, we aimed to design a motor and battery operated kart. The major difference between an electric kart and a go-kart is only of the power source. The static and dynamic behaviors of the go-karts were studied in order to eliminate the other existing problems in a go-kart. The designs were iterated continuously in order to maximize the performance. All the subsystems designed had separate design considerations. The overall vehicle was light in weight, highly stable and eliminated most of the current issues with a go-kart. The kart could pass through all the static and dynamic tests put forward in order to prove its excellence.

2. Design & Fabrication of Frame

While designing the frame, the main aim was to make it as light as possible to maximize power to weight ratio. Secondly to make the frame strong enough to withstand static loads and impact loads. The other design considerations kept in mind were to make a compact & durable vehicle with low Centre of Gravity and adequate driver safety. Low centre of gravity ensures better stability to the vehicle. Simple ladder frame was designed by placing beams as support for driver and other chassis components. The final arrangement in the frame used multi planar structures that added overall rigidity to the frame and giving ample space for placing all the occupant related components. Further side support structures were also added to increase load stability and load carrying capacity of the chassis. Bottom to top approach was applied. Lightest possible frame was first designed and then structural members were added to it one by one by iteration process taking Finite Element Analysis as a criterion for frame propagation. The design of frame and assembly of the vehicle was done on Solidworks 2014.

Fig 1: **Isometric View of frame**

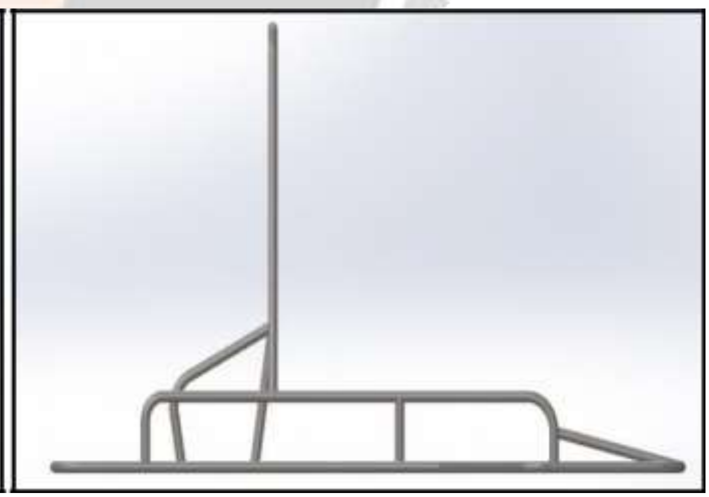


Fig 2: Side View of frame

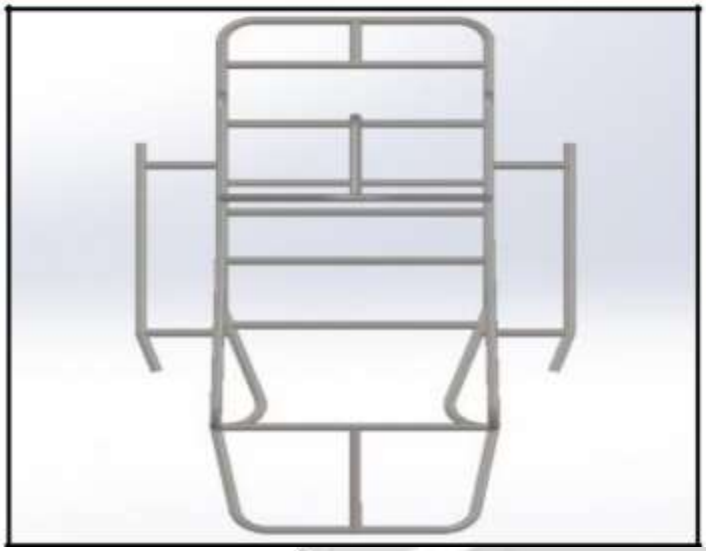


Fig 3: Top View of frame

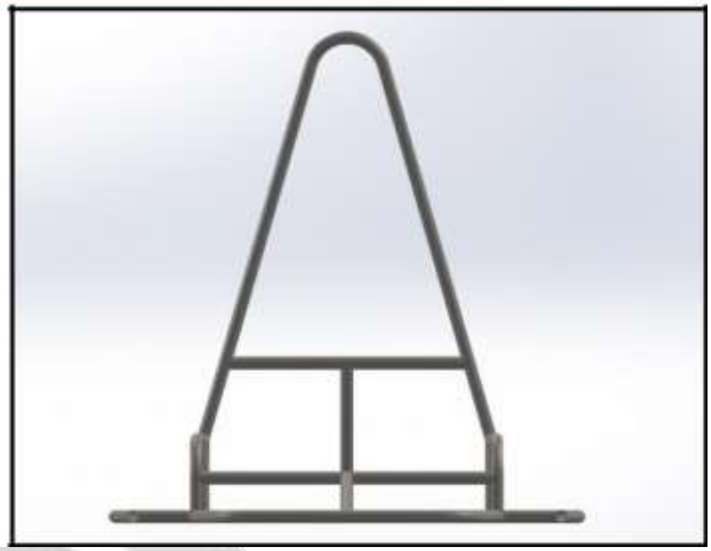


Fig 4: Front View of frame

The frame had

- Wheelbase = 45 inches
- Track width = 36 inches

2.1 Frame Material Selection

The selection of material plays a very crucial role in order to achieve desired weight, strength, safety and endurance of the vehicle. To make an optimal material selection extensive study of materials on the basis of mechanical properties, chemical properties, cost and availability was done. Yield strength, Ultimate tensile strength, density, bending stiffness, welding required and elongation percentage were the key parameters for the final selection. Finally grade 304 of Stainless steel was chosen as the material for fabrication of the frame.

Stainless Steel is a steel alloy with a minimum of 10.5% chromium content by mass. Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. However, it is not fully stain-proof in low-oxygen, high-salinity or poor air-circulation environments. Stainless steel is used where both the properties of steel and corrosion resistance are required.

The pipe size determines the strength and load carrying capacity of the frame. Circular cross-section pipe of outer diameter 25.4 mm and the wall thickness is 2 mm was selected.

2.2. Analysis of Frame

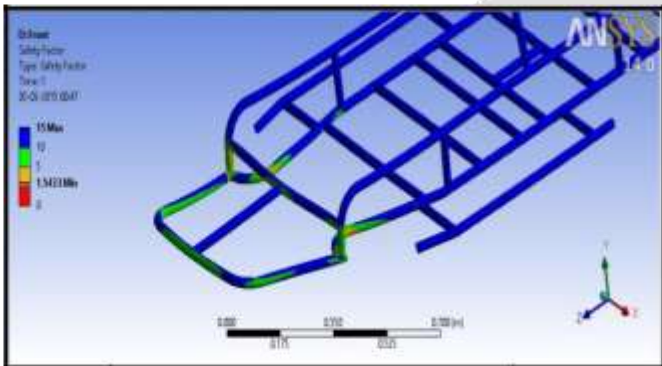
Simulation of Load analysis was also performed using Finite Element Method (FEM) and results showed that the chassis designed was able to sustain all the vertical loading & impact loads like front impact, rear impact and side impact respectively. Fig.4 to Fig.8 shows the results of analysis conducted on the frame.

Ansys WB 14.0 was used for analysis of frame. After several iterations meshing size 10 mm was finalized with Beam element. Beam element was chosen as it is applicable to ladder & space frames and it is faster than shell method as solver assumes beam simplification in the model.

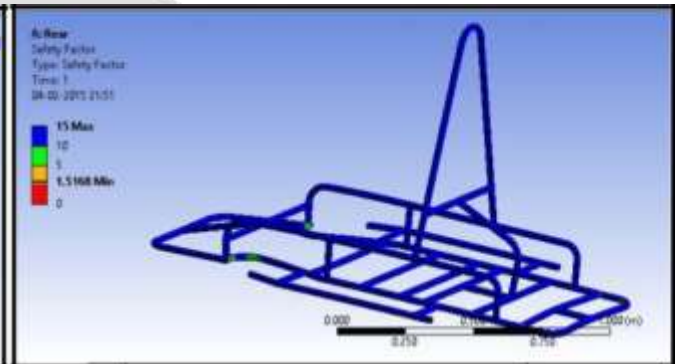
To calculate the impact force, Impulse equation was used. The rate of change of momentum for this a vehicle of mass 170 kg was assumed to hit the vehicle with an oncoming velocity of say 40 kmph i.e.11.11 m/s. In case of an elastic collision with impact duration of 0.3sec (generally ranges between 0.1-0.5 secs) the impact force obtained is:

F = Mass * Velocity / Impact time

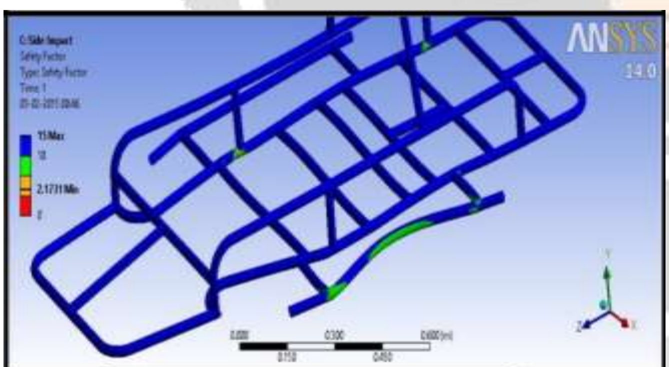
F= 170*11.11/0.3 = 6295.6 N say 6300 N



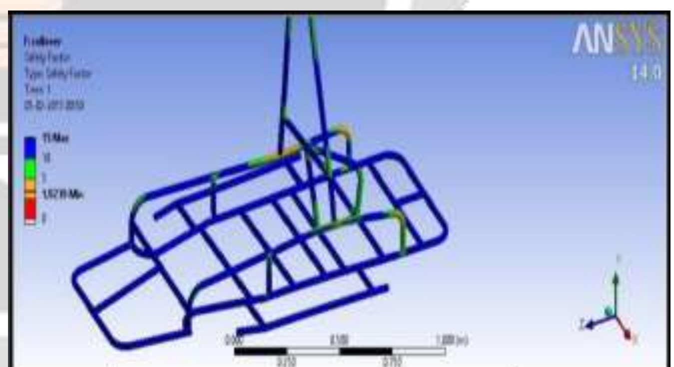
: Front Impact Test
FOS = 1.54



Rear Impact Test
FOS = 1.51



Side Impact Test
FOS = 2.17



Rollover Test
FOS = 1.92

The results of CAE indicated that design of frame was successful as it was not only light weight but could withstand all the tests which ensured driver safety & reliability of the frame.

3. Steering Geometry

The design considerations while designing the steering system of the kart included the following aspects:

- Less Steering effort.
- Minimum Turning radius.
- To achieve Pure rolling.
- To minimize Bump steer.
- To obtain Directional Control Stability.
- Optimum Steering response

Keeping in mind all these aspects, the chosen steering design included a Knuckle (linkage type) steering geometry rotated with the help of an ambassador- water body bearing situated at the apex of the knuckle and the dimension were iterated using 'Peter Eland knuckle spreadsheet' so as to achieve pure rolling with minimum steering effort. The design of knuckle is depicted in Fig 9.

The Ackermann principle was used (but not perfect Ackermann i.e.100%) to determine the different values related to this geometry which are included in Table 1

: Steering Knuckle

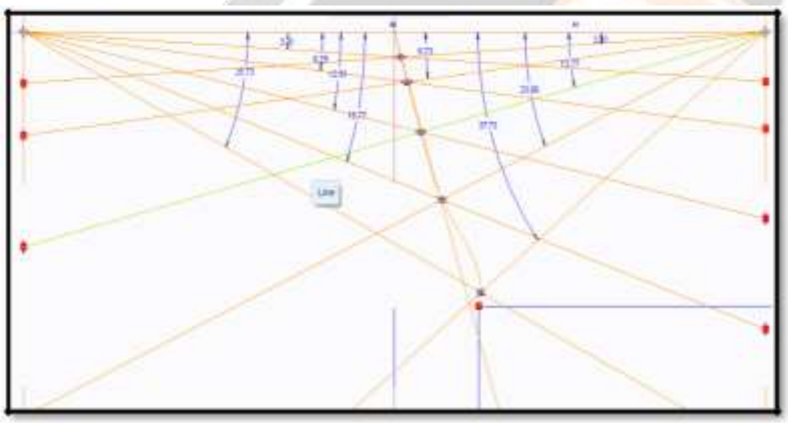
Parameter	Value
Turning radius	2.4 m
Lock angles	29° & 40° (for outer & inner)
Ackermann percentage	111.70 %
Type	Oversteer
Steering effort	9 N-m(60N) at steering wheel
Ackermann angle	15 °
Tie rod length	329.5 mm
Knuckle base lengh	48 mm
Steering arm length	70 mm

: Parameters ofSteering Geometry

The other main objective i.e. 'Pure Rolling' was also achieved to a great extent with the help of Peter Eland spreadsheet which provided errors that could be iterated as many times as desired. Thus, finally a pure rolling curvature was obtained up to 3 meter of turning radius and after that, the Ackermann percentage started increasing up to 111.7% at the tightest turn.

The innovative part in the steering system was designing and fabrication of a Detachable steering wheel. This allows driver of any height to sit comfortably & then fit the steering wheel.

Also, simultaneously with the iterations of pure rolling and Ackermann principle, we iterated with bump steer conditions with the help of Lotus analyzer to attain least toe change with max of 2 inches of wheel travel. Thus we attained minimal toe change leading to conditions of no bump steer. So, to put it in a nut shell we have iterated Ackermann theory with Peter Eland's Spreadsheet and also with Lotus Analyzer to find the best suited geometry for steering which can fulfill all the design considerations and can finally lead us to a very strong and effective compromise between various elements giving excellent stability to the vehicle and driver.



Steering Error curve

Detachable Steering

4. Braking System

The main focus while designing the brakes of the kart was not only on brakes efficiency but also on the braking efficiency. Following are the design considerations kept forward while designing & assembly of braking system:

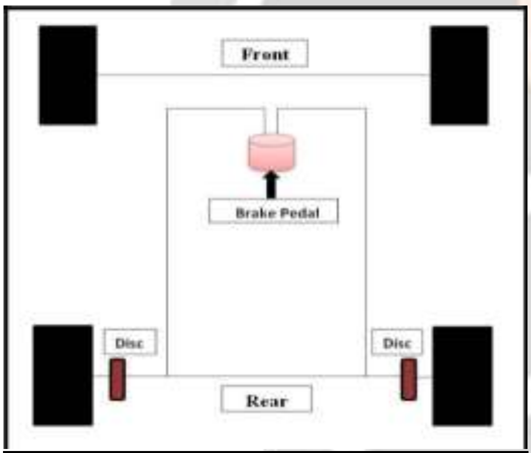
- Effective braking in all conditions.
- Less driver fatigue.
- Simple and reliable brake system
- Adequate braking force capable of locking both rear wheels simultaneously.

A hydraulic circuit is designed in accordance with the vehicle weight, vehicle length and top speed. For good handling brakes should be consistent, use only a moderate amount of pedal force and should be free of fade in its hardest use. The work a disc brake has to do and the heat it has to dissipate during braking, are directly proportional to the weight of the vehicle and its speed when the brake is operated. The hardest working conditions occur with maximum load and maximum speed. Initially we thought to install brakes on all the four wheels of kart but looking at the weight distribution of our kart, being biased much on the rear side of the cart carrying the motor and the batteries, we decide to install disc brakes only on the rear wheels to save cost also.

A Bosch tandem master cylinder (along with a brake oil reservoir) connects to the pedal through the pushrod. The master cylinder is connected to the disc brake assembly fitted on the rear transmission shaft through brake lines. As the brakes are applied, the transmission shaft is being slowed down (or) partially stopped and then the wheels are simultaneously stopped. Honda CB Shine calipers along with Honda Aviator Disc were used.

The innovative part in braking system is the use of 'Brake over Travel Kill switch' which automatically cuts off the current supply to motor in case the braking system fails and there is an over travel in brake pedal. This causes the vehicle to slowly decelerate even if brakes don't work. A hand brake has also been provided keeping in mind the safety prospective of the driver.

Braking calculations were done at a velocity of 40 kmph considering the vehicle weight as 170 kg and results are shown in Table 2.



: Layout of braking circuit

Parameter	Value
Brake Pedal Force	100 N
Pedal Ratio	4 : 1
Fluid Pressure	1033335.4 N/m2
Braking Force	438.43 N
Braking Torque	61.25 N-m
Stopping Distance	11.9 m
Brake Fluid	DOT 4
Max. Deceleration	0.525 g

Parametersof braking circuit

The thermal analysis of the disc has been carried out, to ensure reliable performance of braking system. ANSYS Workbench 14.0 has been used for the analysis. Following parameters have been considered for carrying out the thermal analysis:

- Vehicle's kinetic energy considering the vehicle velocity as 40 kmph.
- Heat flux generated based on the kinetic energy

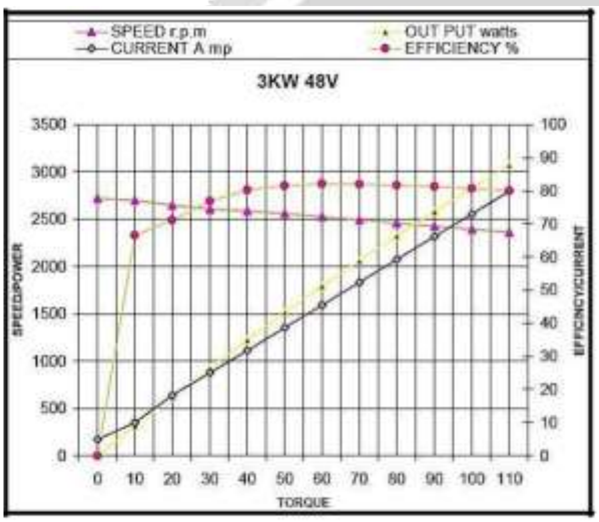
The thermal analysis revealed a maximum temperature of 114.6° C which is pretty safe under normal braking conditions along with deformation in disc as .119 mm.

5. Power Train

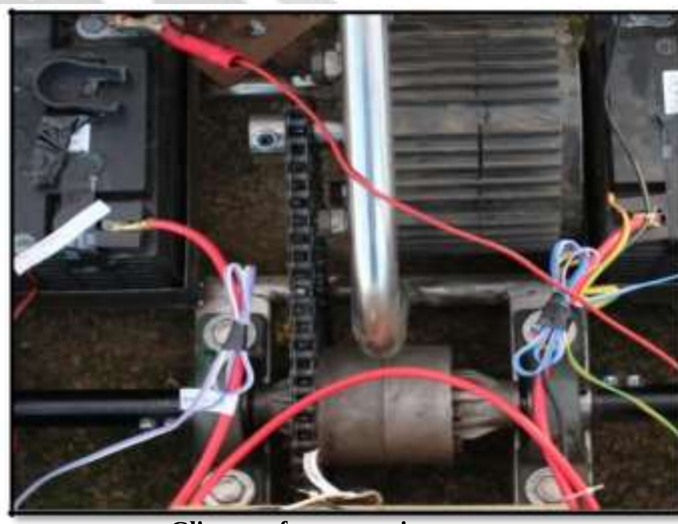
On the basis of performance, reliability, cost and availability a 4KW BLDC motor was chosen to power the vehicle. The motor was capable of providing a peak torque of 12.43 N-m at 2362 rpm. The motor could give an output of 3072 W with a total efficiency of 80.05 %.

The powertrain is the heart of a vehicle as it provides the driving force to run the vehicle. Powertrain was very critical to design as this is what creates a difference between a go-kart and an electric kart. A lot of insistent study was done which brought out the final design after numerous iterations. Following are the design considerations put together for the design:

- Maximize Power to Weight Ratio
- Reliable and durable powertrain
- Less driver fatigue
- Optimum compromise between max. speed and acceleration.
- Efficient and compact power train



: Performance curve at 48VDC



: Glimpse of power train

The design parameters of the powertrain have been summarized in Table 3

Parameter	Value
Rolling Resistance	25 N
Aerodynamic Drag	14.3 N
Traction force	233.24 N
Gear Ratio	≈3:1
Torque at wheels	38.07 N-m
Acceleration	0.14g
Max. Speed	41.46 kmph

: Performance parameters

6. Safety Measures

The safety features incorporated while designing and fabrication of the kart are as follows:

- The frame was designed such that it can outlast all sorts of static and impact forces put on to it.
- The design of frame involves Side Impact Absorber along with front and rear bumpers. So in case of any side collision with any other vehicle or obstacle the driver won't be harmed in any case. Minimum shock will be experienced as certain distance has been maintainedbetween driver seat and Side Impact Absorbers, also there is no direct contact between the two(Refer fig 1).
- The roll hoop is a single bar behind the driver that provides moderate roll-over protection. It has been designed such that in case a roll over happens, the driver is significantly protected from any major injury.(Refer fig 1)
- The kart has been equipped with a 1kg cylinder of Fire extinguisher used for Electrical fire.

  The cylinder was clamped to roll hoop so that it's easily accessible to driver as well as any random person nearby the kart.
- Proper calculations have been done even on the spring used in detachable steering, so that in no case steering is detached itself.(Refer fig. 13)
- Brake over travel kill switch has been used to cut off the current supply in case the braking system fails.(Refer fig 19)
- A manually operated kill switch has been provided on side of dashboard, so that driver can turn off the kart in negligible time and abandon it in case of any malfunction. (Refer fig. 21)
- Temperature Sensors have been used in order to monitor the temperature of batteries continuously. Audible beeps are generated in case temperature of a battery exceeds 50°C. (Refer fig. 20)
- The controller is also equipped with Over Temperature Trip and Low Voltage Trip for safe operation of motor and controller.

Following innovative features have been integrated in the kart to have better performance, comfort and stability in the kart:

- Digital Speedometer has been installed on the dashboard of the kart. The motor used has a hall sensor embedded in it which gives the R.P.M. of the motor shaft. The controller converts the R.P.M. to speed which is then displayed on the digital speedometer. (Refer fig. 20)
- Digital Odometer displays distance travelled by the kart along with the Trip in it which records the distance travelled by kart in one run.(Refer fig. 20)
- It is difficult to park the vehicle as it is of Direct drive type. Slow movements of the kart are not possible. Therefore, to facilitate safer and precise parking, separate 'Parking Mode' can be enabled in the kart through a switch on dashboard. In the parking mode the speed of the kart is reduced to quarter of its original speed, i.e. zero to quarter speed on full throttle pedal press, giving more control over the kart.
- Whenever a go kart tends to take a turn, it tends to slip as the inner and outer wheel need to travel different amount of distances. Now with the use of differential, this kart can not only easily take a turn but also same amount of power is available on both the rear wheels.
- Light Dependent Resistor has been used to switch ON the Headlights automatically in the absence of light. Sensor works on the principle of Photoelectric effect (Refer fig. 21).
- Use of detachable steering allows the driver to have a comfortable sitting position and then put on the steering wheel.(Refer fig.13)

7. Conclusion

Through this paper, we aimed to design a vehicle with integration of both electronics as well as mechanical models and also to present it aesthetically and ergonomically strong. With a very light and strong frame, pure rolling steering, efficient braking system and optimum power to mass ratio the kart easily fulfills all the static and dynamic tests put through. Thus the kart is built with effective compromise between each and every section to attain best possible stability, speed, acceleration, response, safety and feel. The vehicle was designed and tested in the national event 'SAE Eco-kart 2015' where it could clear all the Static and Dynamic Tests in 1st attempt and obtained an All India Rank-4 with Best Innovation Award.

8. Future scope

The future scope of this research can be aimed towards design of hybrid karts, solar powered karts, fuel cell powered karts, and hydrogen powered karts in order to reduce the use of fast depleting fossil fuels. Aerodynamic studies can play a major role in future if the karts are designed for high speeds.

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