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RESEARCH ARTICLE

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DESIGN AND ANALYSIS OF CHASSIS FRAME OF MONOSEATER FOUR-WHEELED VEHICLE

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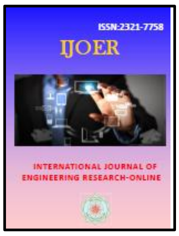


ABSTRACT

The team intends to design and manufacture a safe, durable, reliable and high performance go kart. The present paper aims to design and analyse a Go-kart chassis consisting of circular hallow pipes. Modelling, simulation and analysis of a Go-kart chassis are performed using software's i.e. CATIA V5 and ANSYS. The maximum displacement or deflection is determined by using static analysis of the frame. The computed results are then compared to the analytical calculation, where it is found that the location of the maximum displacement agrees well with the theoretical approximation.

The report provides detail explanation about all the subsystems like chassis, steering, braking and power train. The report covers validating, theoretical calculations, simulations and optimized results.

I. INTRODUCTION

We approached our design by considering all possible alternatives for a system & modelling them in CATIA and subjected to analysis using ANSYS software. Based on analysis result, the model was modified and retested and finalized a design.

The main objective of the team is to ensure a perfect design so that it completes all the tasks without any breakdowns. Overall, the final product is expected to have an efficient cost-structure, incorporating innovative concepts, high durability and performance, vibration dampening engine mounts, and ergonomic seating.

In order to meet the design objectives, the team was divided into groups, with each group being responsible for specific subsystem of the kart. The major sub-systems of the go kart are:

1) Chassis
2) Engine, Power Train and Electrical System
3) Steering System
4) Braking System
5) Wheel axle and safety fittings

II. CHASSIS

A. Chassis: The chassis or the base frame is the main part of the vehicle on which remaining parts are mounted. It should be extremely rigid and strong to withstand shocks, twists, stresses and vibrations. It is narrow in the front for providing short turning radius to front wheels and widens out at the rear to provide larger space in the body.

B. Design Objective: The objective of the chassis design is to produce a durable and maintainable frame keeping in mind the safety of the driver, cost, quality, weight and overall performance of the vehicle. Other design factors include durability and maintainability of the frame.

C. FRAME CONFIGURATION: With limited power, the focus was primarily on the power to weight ratio of the vehicle. With the engine limitation, the only means to improve this critical parameter was to reduce the overall vehicle weight. Great care was taken in laying out the chassis in order to accomplish this.

D. MATERIAL SELECTION:

The material used in the vehicle must meet the requirements and as the vehicle will be used for racing, the weight is a crucial factor and must be considered. The proper balance of fulfilling the design requirements and reducing the weight was crucial for a successful design. We initially considered to check the suitability were AISI 1018, 1020, 1026 and 4130.

Benchmarking was done to select the material by comparing various properties of each material.

TABLE I: COMPARING DIFFERENT MATERIALS

MATERIAL	MODULUS OF ELASTICIY	YIELD STRENGTH	ELONGATION AT BREAK
AISI 1080	29700	53.7	15%
AISI 1020	29700	42.7	36%
AISI 1026	29700	60.12	15%
AISI 4130	29700	63.1	25.50%

As we know, the increase in yield strength affects the bending strength of a material, and it is not only effected by cross-sectional moment of inertia but also by radius of material. Thus CHROMOLY i.e. AISI 4130 having maximum yield strength would allow the use of large diameter tubing with smaller wall thickness.

1.Dimensional Specifications: Seamless tubes of side outer diameter 32mm, inner diameter 26mm and thickness 3mm.

2. Justification: Square pipes are much difficult to bend compared to that of round pipes. As the chassis consists of bends, round pipes are chosen for the chassis. Round tubes have high moment of inertia and are easy to bend. At the same time they give high torsional and bending moment strength. The reduced weight of round pipes further adds to the advantages of using round pipes.

E. Basic frame:

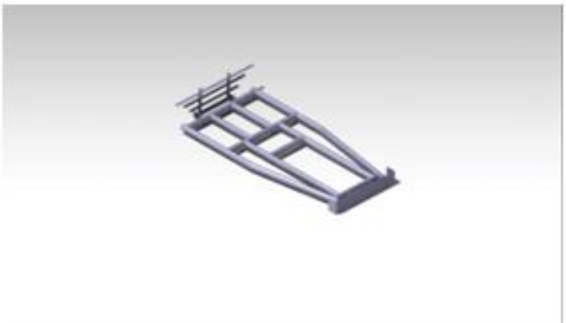


Fig.1 basic frame

CATIA models of our frame and kart in different views:

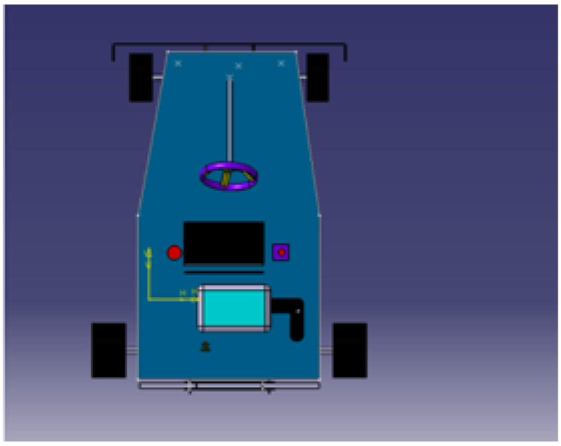


Fig.2 top view of kart

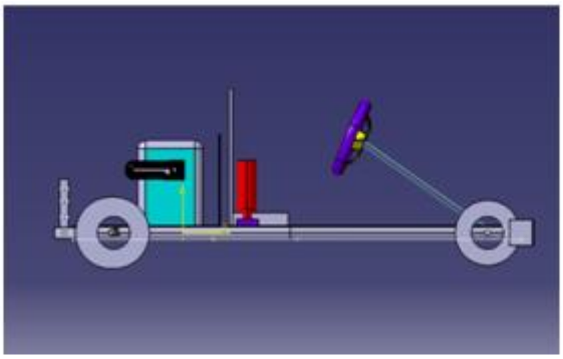


Fig.3 side view of kart

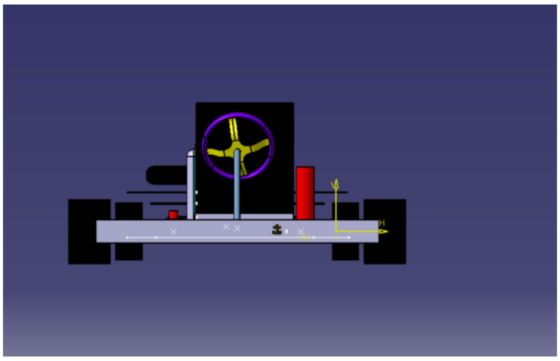


Fig.4 front view of kart

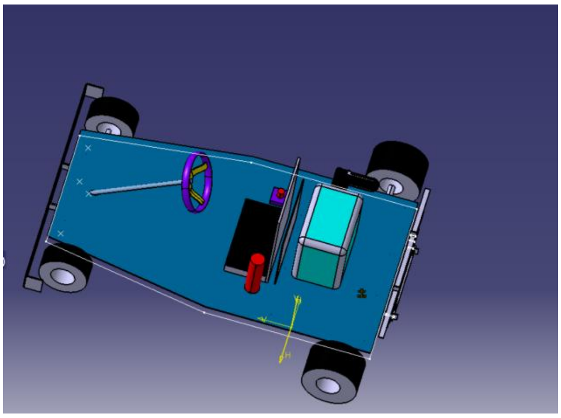
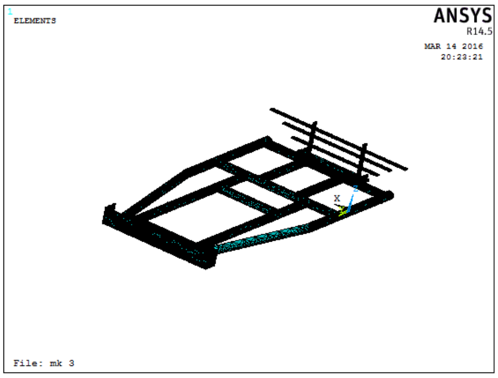


Fig.5 3-d view of kart

F. Frame Analysis in ANSYS: The vehicle design is tested for the correctness and stability under the scenario of extreme shocks and loads acting in case of any mishap during the operation or racing. The Analysis is done using ANSYS Software to find out the effect of the following:

1.Meshed model: In this the vehicle frame is meshed into triangular shapes. The meshed model is show below:

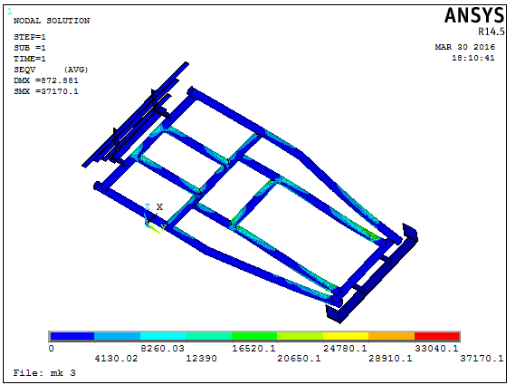


2.Front Impact: In this analysis the vehicle is subjected to high amount of impact force from the front assuming that the vehicle is moving at the highest velocity 45km/h (max. speed of kart) and goes and hits a steady obstacle and deforms in an impact time of 0.5 seconds. The force is calculated as follows:

Force = Rate of change of momentum F = m (v-u) /t = 150 x (0 – 12.07) /0.5 = 3621N

This load is assumed to be acting on the front impact members of the chassis frame and the deformation that is attained is determined.

Result – Front Impact:



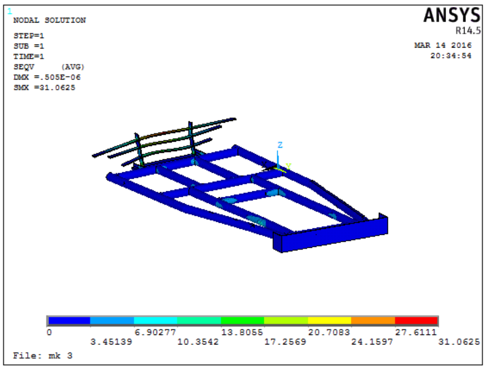
The maximum deformation obtained is about 0.064m which is near the end of the front impact members and is hence in the acceptable range.

Also the maximum stress acting on the frame is 356 Mpa and these acts at the ends of the front impact member and hence the structure can be considered as a safe one with an average Factor of Safety of 1.33

3.Rear Impact: In this analysis the vehicle is subjected to impact forces from back. It is assumed that the vehicle is in its own inertial state and other vehicle moving at the highest velocity comes and hits it from the back. The force is calculated as follows:

F = m (v-u) /t = 180 x (0 – 15.6) /0.5 = 5616 N This force is assumed to act on the rear impact members of the chassis frame and the deformation is attained.

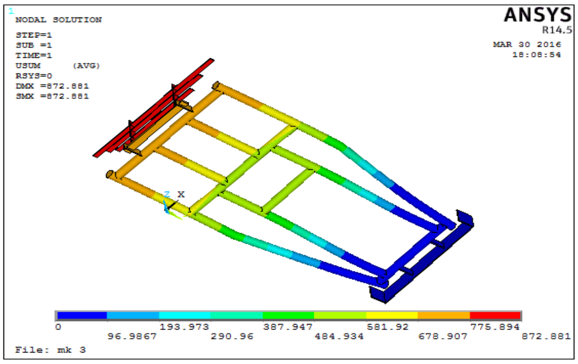
Result – Rear Impact:



The maximum deformation obtained in this case is about 0.108m which is in the acceptable range. Also the maximum stress acting on the frame is 289 Mpaand this act at the ends of the rear impact member and hence the structure can be considered as a safe one with an average Factor of Safety of 1.45.

4.Total displacement vector sum: In this analysis the vehicle is subjected to load on total frame.The young's modulus of the material is 210. i.e, E=210Gpa, density ρ=0.00000785 kg/m^3, μ=0.3,load applied= 50N

The total displacement is $0.505*10^{-6}$ mm



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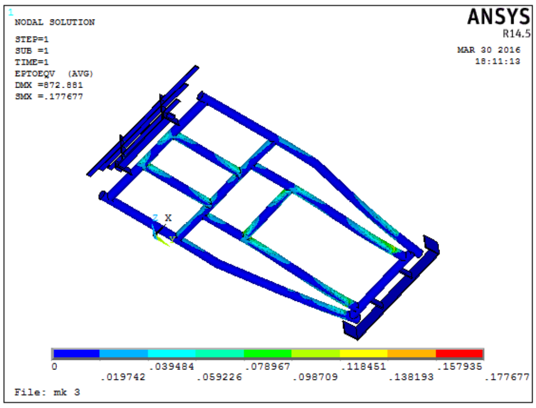
5.Total mechanical strain:The range of total mechanical strain obtained is from 0.14 to 0.16*10^(-9)



III. ENGINE ,POWER TRAIN AND ELECTRICAL SYSTEM

The engine is the main energy source of the kart which propels the kart with the help of a drive train and transmission system.

A.ENGINE DESIGN AND MOUNTING: The placement of engine was designed keeping in mind the dimensions, seating arrangement, rear axle and firewall placement. The engine was placed slightly right side to the longitudinal axis on back of driver's seat exactly so that the entire weight is symmetrically spread when the battery is placed on the opposite side. Also vibration dampening material was placed below the engine mounting points to curb all the vibrations coming from the engine and to have a more comfortable ride.

*B. POWER TRANSMISSION:*The transmission that occurs in our system is through centrifugal clutch which acts as a drive shaft.The centrifugal clutch works on the principle of centrifugal force, which increases proportional to the square of rotational speed. And also it does not require clutch pedal for operation of the clutch.A centrifugal clutch uses centrifugal force for engagement and disengagement of clutch to drive shaft.Centrifugal clutch is used in automatic transmission.The driven shaft (or) jack shaft had a two spoilers one is connected to the drive shaft with the help of chain belt and another is connected to the spoiler of rare wheel shaft. When the engine starts working the drive shaft rotates which drives the jack shaft. Due to this the spoiler of rare wheels also rotates while rotating the jack shaft .Thus the power that transmits from engine to rare wheels to move the cart ahead.

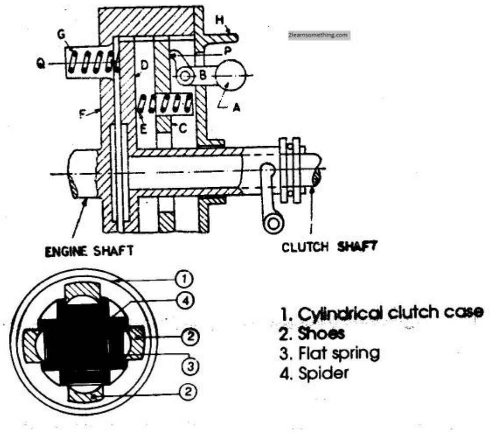


Fig.6 centrifugal clutch

TABLE II: ENGINE SPECIFICATIONS:

Ship weight	35.0 lbs
Engine displacement (cc)	127
Start type	Recoil
applications	Mid duty chore applications
Engine type	550 series
torque	5.5
Ruel tanks capacity	2
Ignition system	Electronic
Cylinder	1
Cooling system	Air cooled
Max rpm	3,300

C.ENGINE KILL SWITCH: The last function of the electrical system is to shut off the engine. Two switches are provided in the vehicle, one within reach of the driver and the other within reach of an observer. A simple waterproof toggle switch is positioned in the vehicle with in easy reach of the driver, while a emergency style push/pull switch is located at the rear of the vehicle. One wire from each switch is connected to the kill wire on the engine while the other switch wires are grounded into the chassis. If either switch is flipped, the magneto in the engine is grounded and thus shutting down the engine. All wires are run through plastic flex conduit, ensuring that they are not damaged during normal operation. The system is simple and inexpensive. Its simplicity ensures that it is reliable while providing the necessary functions.

IV. STEERING SYSTEM

The objective of the steering system is to provide directional control of the vehicle to the driver with minimum input.

A. *Steering System Requirements:* For proper and smooth operation and performance of the system, the steering system of any vehicle should fulfill the following requirements:

- ✓ The steering mechanism should be very accurate and easy to handle.
- ✓ The effort required to steer should be minimum and must not be tiresome to the driver.
- ✓ The steering mechanism should also provide the directional stability. This implies that the vehicle should have tendency to return to its straight ahead position after turning.
- ✓ It should provide pure rolling motion to wheel.
- ✓ It should be designed in such a manner that road shocks are not transmitted to driver.

B. *Function:* Functions of the steering system are as follows:

a) It helps in swinging the wheels to the left or right.
b) It helps in turning the vehicle at the will of the driver.
c) It provides directional stability.
d) It helps in controlling wear and tear of tyres.
e) It helps in achieving the self-rightening effect.
f) It converts the rotary movement of the steering wheel into an angular turn of the front wheels.
g) It multiplies the effort of the driver by leverage in order to make it fairly easy to turn the wheels.
h) It absorbs a major part of the road shocks thereby preventing them to get transmitted to the hands of the driver.

C. *Main Components of Steering System:*

The following are the main components of steering system are

1. Steering Wheel
2. Steering column or shaft
3. Steering Gear
4. Drop Arm or Pitman Arm
5. Drag Link
6. Steering Arm
7. Track-Arms
8. Track Rod or Tie-Rod
9. Adjusting Screws

D. *STEERING MECHANISM:* We are going to use four bar linkage mechanism in our kart. The reason behind this decision is that the kart has to take sharp turns in the competition, so by using this type of mechanism the driver has ease and much control over the turn. And by using four bar mechanism minimizing of steering ratio up to 1:1 is possible. That means if the driver turns the steering wheel 1 degree the kart wheels also turns 1 degree.It means that if the steering wheel is rotated for 1 degree, the inner wheel turns 1 degree. As steering ratio increases, the steering effort required to turn the wheels decreases.

E. *ACKERMANN STEERING PRINCIPLE:* The Ackermann principle is based on the two front steered wheels being pivoted at the ends of an axle-beam. The original Ackermann linkage has parallel set track-rod-arms, so that both steered wheels swivel at equal angles. Consequently, the intersecting projection lines do not meet at one point. If both front wheels are free to follow their own natural paths, they would converge and eventually cross each other. Since the vehicle moves along a single mean path, both wheel tracks conflict continuously with each other causing tyre slip and tread scrub. Subsequent modified linkage uses inclined track-rod arms so that the inner wheel swivels about its king-pin slightly more than the outer wheel. Hence the lines drawn through the stub-axles converge at a single point somewhere along the rear-axle projection.

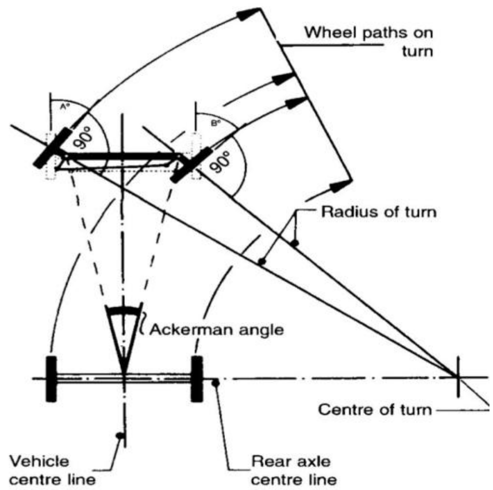


Fig.7 Ackermann principle

Why Ackermann geometry is used?

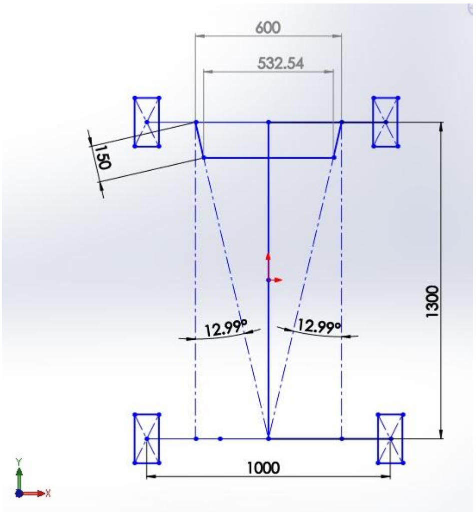
- It is to avoid the need for tires to slip sideways while following the path around a curve.
- This steering system consists of turning pairs which helps while following curved path.

F. Steering System selection , Results and Calculation:

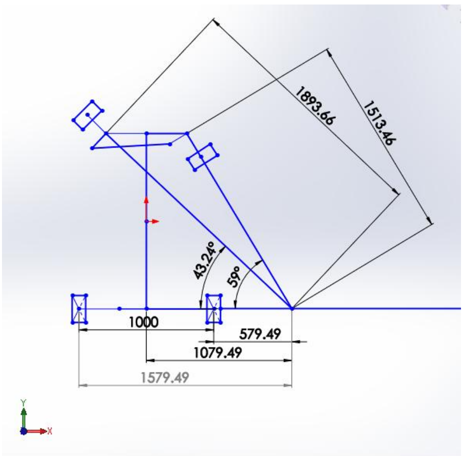
After a comparative study on different steering systems that are available in the market, the double 4-bar mechanism was chosen for our go kart due to the following reasons:

- Cheaper than other systems.
- Simple to fabricate.
- Less steering effort required.
- Increased steering responsiveness.
- Less turning radius can be achieved.

The steering system used in our vehicle has its tie rod directly connected to the steering rod in the ratio of 1:1. The Ackermann angle of this type of steering is calculated as follows:



Track width (TW)	a = 1000 mm;
Wheel base (WB)	b= 1300 mm;
Distance between Pivot& wheel	e = 200mm;
Pivot centre distance	c = a-2e = 1000-2*200 = 600mm;
Ackermann angle	α = 17.10 deg;
Steering arm length	r = 150 mm;



Tie rod length = 532.54 mm;

Now the value of inner wheel after turning θ is calculated for correct steering. This can be done correctly by drawing a graph between θ and (cotΦ-cotθ).

Using relation, sin(α+θ)+sin(α-Φ)=2sinα

Let θ= 50 deg;

Using 'α 'value and from above equation,

Φ =39.22 deg;

Now, cotΦ - cotθ =1.225-0.839= 0.386;

Let θ= 57 deg;

Using 'α ' value and from above equation,

Φ =42.37deg;

Now, cotΦ - cotθ =1.096-0.649= 0.447;

Let θ= 59 deg;

Using 'α ' value and from above equation,

Φ =43.12deg;

Now, cotΦ - cotθ =1067-0.6= 0.467;

We know the condition for correct steering

i.e, cotΦ - cotθ = c/b

cotΦ - cotθ = 600/1300

cotΦ - cotθ = 0.462 deg;

For correct steering θ=59 deg; Φ=43.12 deg;

Therefore for correct steering we plot a graph as show below:

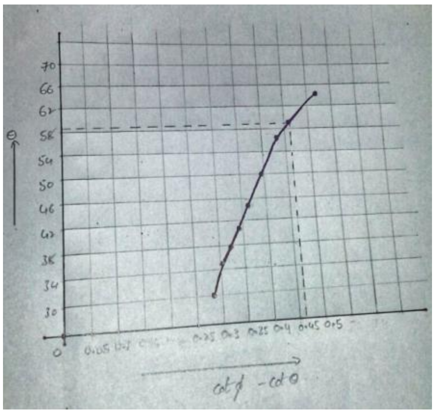


TABLE III: STEERING SPECIFICATIONS

STEERING PARAMETER	VALUE
TOE IN	1º
CAMBER	-1.5º
CASTER	2º
STEERING RATIO	1:1
TIE ROD LENGTH	26.0"
ACKERMANN ANGLES	43.24º ,59º
TURNING RADIUS	1.89m

V. BRAKING SYSTEM

Brake is a device for slowing or stopping a moving vehicle, typically by applying pressure to the wheels.

A. ***Hydraulic brake:*** The hydraulic brake is an arrangement of braking mechanism which uses brake fluid, typically containing ethylene glycol, to transfer pressure from the controlling mechanism to the braking mechanism

B. ***Braking system:*** We have decided to use hydraulic disc brakes on all four wheels of the car. The main reasoning behind this is that it is a less complicated system and requires less maintenance than mechanical brakes. When the driver steps on the pedal, a pushrod acts on the piston in the master cylinder, causing the brake fluid to compress and pressure to build up in the cylinder and in the brake lines. The brake lines connect the master cylinder to the calliper, located at the rotor at the wheel. The brake fluid then travels through the brake lines and pushes on a piston in the calliper. The image below shows the pushrod (on the far right) pushing on the primary piston, compressing the fluid and sending it out the brake lines. When the piston in the calliper is acted upon, it causes the brake pad to squeeze against the rotor. Since the rotor and the wheel are mounted to the same axle, when the rotor slows down, the wheel also slows down. In the picture below, the yellow colour on the right represents the brake fluid reaching the calliper through the brake line. The brake fluid pushes against the piston.

The parts are as follow:- 1. Brake Pedal - Operated by the driver. 2. Brake booster - Provides the brake easier to apply 3. Master cylinder - Provides hydraulic pressure 4. Calliper and Disc - Slow or stop the wheels when the brake callipers at the wheel. 5. Brake lines and Hoses - Connect the master cylinder to the calliper at the wheels 6. Brake Fluid - Transmits force from the master cylinder to the callipers at the wheels. 7. Connector Rod - Connected from brake pedal until master cylinder to transmit the pressure when pedal is apply.

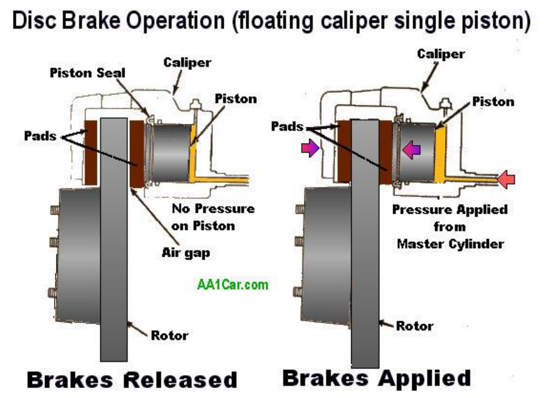


Fig.8 Disc brake operation

TABLE IV: BRAKING SPECIFICATIONS:

Pedal effort	20kg
Diameter of master cylinder piston	3.51cm
Force on master cylinder piston	1177.2N
Area of master cylinder piston	$9.676*10-4m^2$
Maximum hydraulic pressure developed	5.94MPa
Area of caliper piston	$9.67* 10-4m^2$
Clamping force	5743.98 N
Breaking torque developed	175N-m
Breaking torque developed	$163.08N^{-m}$
Retardation	$6.867m/sec^2$
Stopping time	1.757seconds
Stopping distance	10.7m

- **Advantages:** All of the four cylinder total braking effort is equal for each.
- System construction is very simple.
- Less rate of wear.
- High mechanical advantage.
- **Disadvantages:** Sometimes fluid makes the system useless when slight leakage.
- For intermittently brake the hydraulic system is suitable to be applied.

C. **Calculation:** Pedal effort = 20 kg

Force on master cylinder piston (Fmcp) = pedal effort x pedal ratio

= (20 x 9.81) x 6

=1177.2 N

Diameter of master cylinder piston (Dmcp) =1.38 inch (3.51 cm)

Area of master cylinder piston = Amcp =π/4 x (diameter of master cylinder piston)^2

=9.676 cm^2

Maximum hydraulic pressure developed =Fmcp x Amcp

=5948458.818 Pa

= 5.94 MPa

Clamping force = Maximum hydraulic pressure x Total effective area of calliper piston

= (5.94)x(106) x(9.67) x(10^{-4})

= 5743.98 N

Brake torque developed =Clamping force x µ x effective radius

Where µ - coefficient of friction between rotor and calliper

Brake torque developed = (5743.98) x (0.3) x (4)x (2.54) x (10^{-2})

=175 N-m

Brake torque required =Brake force * Rolling radius

=(170 * 6.867)* 0.1397

=163.08 N-m

Retardation = µ *g

Where µ = coefficient of friction between tyres and ground

Retardation = 0.7x 9.8 m/sec^2 = 6.867 m/sec^2

Stopping time = (v-u)/a

Where v - final velocity

u - Initial velocity

a - retardation Stopping time =(0-12.07)/6.867 = 1.757 seconds

Stopping distance = ut +1/2(at2)

= (12.07 x 1.757) + (0.5)(-6.867)$(1.757)^2$

= 10.60m

VI. WHEEL AXLE AND SAFETY FITTINGS:

A.Wheels:

1.Selected tyres:

4.5*10-5– front tyre

7.1*11-5– rear tyre

2. Front tire : slightly inclined (top-in & bottom-out)

There are different style sidewalls, and this is probably the most important thing to you as a consumer, you may want a stiff side wall, or you may want a soft sidewall, it depends on the application. But on a go kart that you are dealing with on a track, you want some stiff sidewall tires. The reason for that is when you try to corner the tire itself will actually bole over or bend. It is not something that you want to happen. But tires with desired stiffness of sidewalls are relatively expensive. Hence, we have decided change the geometry of you front wheels so that they are canted a little bit that helps in cornering, in that the forces will tend to go more vectorly through the tire and cause it to bend less.

3.Tire Size: Front-Small & Rear-Large

The smaller tire is up front and the reasoning for that is it is easier to steer, there is less kick back in the steering system, less rotational inertia in the tires, and it is more manageable.

The rear tires are larger, they are designed for traction during acceleration and for cornering, because you have a little bit more weight in the rear, and the front tires have less weight on them, that is why they are a little bit smaller. The diameter are typically the same, but the widths are different.

4.Tire Width: Front-Narrow & Rear-Broad

The basic reason for having the rear track wider than the front is due to the weight distribution when a car takes a corner.

A narrow front track width will result in less scrub, providing better turning up front.

B.Axle :

1.Rear Live Axle: A live axle means that the wheels are mounted directly to the axle, and the axle spins. A dead axle would be where the wheels spin freely and the axle does not turn.

A live axle on a go kart means that the engine will power both rear wheels at the same speed and power. This is accomplished with a single sprocket mounted to the live axle.

Since both wheels are locked in to the power all the time and when both wheels are turning at the same time, you'll have twice the traction.

This is not to say that live axles don't have their drawbacks. Unfortunately for the on-road set, a live axle means that turning is difficult. This is because both rear wheels turn at the exact same speed.

2.Problem with Live Axle: When making a turn, the outside wheel must be able to spin faster than the inside wheel. If they are forced to turn at the same rate by a live axle, then the outside wheel must slip on the driving surface in order to turn as fast as needed.

C. Safety fittings: Safety of an automobile can be ensured by two main considerations. Firstly, the design should be such that chances of accident happening are minimum and secondly, if accident does take place, the injury to the occupants should be minimum.

1.Safety features of a go kart or racing car:

Frame:The frame is designed by keeping the driver safety in view. Frame analysis is done by ANSYS software and maintained factor of safety less than 2.

Restraints:

We use five-point harness seatbelt, where two straps are for shoulders and down, other two for waist and one is between legs.Straps are made of thick padded nylon.

Fuel tank::

Racing car fuel tank is filled with foam to reduce the amount of airinside, thereby minimizing the chances of explosion.Even in explosion, the foam would absorb the same

VII. DESIGN VALIDATION PLAN

DESCRIPTION	ACCEPTANCE CRITERIA	RESPECTIVE	TEST RESOURCE
3D CHECK	DESIGN DIMENSIONAL TOLERANCE & ACCURANCY	DESIGN DEPT	CATIA SOFTWARE
CHASSIS	MAX FORCE	DESIGN DEPT	CATIA SOFTWARE
WELDING JOINTS	MAX FORCE	DESIGN DEPT	CATIA SOFTWARE
IMPACT ANALYSIS	MAX FORCE	DESIGN DEPT	CATIA SOFTWARE
TRANSMISSION	OUTPUT TOURQUE	TRANSMISSION DEPT	TECHOMETER
IC ENGINE	POWER,TORQUE	TRANSMISSION DEPT	POWER METERING GAUGE
MOTOR	POWER,TORQUE	TRANSMISSION DEPT	POWER METERING GAUGE,VOLTMETER
FRAME	MAX FORCE	DESIGN DEPT	ANSYS SOFTWARE
ELECTRIC TEST	VOLTAGE	ELECCTRONIC DEPT	MULTIMETER
ENGINE TEST	MINIMUM 3"CLEARENCE	DESIGN DEPT	MEASUREMENT TAPE
MATERIAL CHECK	MINIMUM MATERIAL LOSS	DESIGN DEPT	ANSYS SOFTWARE
UTM TEST	STRESS STRAIN ANALYSIS	DESIGN DEPT	UNIVERSAL TESTING MACHINE
BRAKE TEST	STOPPING DISTANCE	BRAKE DEPT	MEASURING TAPE, STOP WATCH
WHEEL ALIGNMENT	TARGET DATA(00MM-0.4MM)	STERRING DEPT	MEASUREMENT TAPE
STEER TEST	REQUIRED TURNING RADIUS	STERRING DEPT	MESUREMENT TAPE
TYRE PRESSURE	22 psi	WHEEL DEPT	PRESSURE GUAGE

VIII. DESIGN FAILURE MODULES AND EFFECT ANALYSIS

Process Step	Sub Assembly	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Occurrence	Design Control	Detection	Action To Be Taken
FRAME	Roll cage	Weld point breakage	Failure of Roll cage	5	Excessive load applied	3	Stronger Welding	7	RE-WELD
		Bending of roll cage	Instability	9	Excessive shear stress	3	Addition cross member	9	REPLACEMENT

ENGINE	Air filter	Air filter failure	Poor mileage	1	Dirt inside the pipe	3	Standard air filter	6	Clean regularly/replace
	Mountings	Mounting joints failure	Excessive noise and vibrations	4	Loose mounting joints	3	High strength nut bolts	4	Use of washers for packing
	Chain	Chain	Kart stops	5	Loose or Tight chain	5	Mount properly	3	Repair/Replace
STEERING	4-bar mechanism	Wire brake	Inability to accelerate	6	Excess use of acceleration	4	Standard access wire	3	Repair/Replace
		Tie-rod-end breaks	Cannot steer	5	High impact forces	5	Proper welding	3	Repair/Replace
		Steering arm joint break	Cannot steer	6	High impact forces	3	Proper welding	4	Re-weld
BREAKING	Hose	Leakage	Ineffective braking	7	Physical damage	3	Properly fitten restricts motion	3	Replace
	Master cylinder	Improper functioning	Ineffective braking	7	Worn out piston	3	Tandem master cylinder with double reservoir	5	Repair/Replace
	Fading	Improper heat dissipation	Ineffective braking	3	Overheating	7	Ventilated disc brakes	7	Replace
FUEL	Fuel	Fuel leakage	Engine stops	6	Damage fuel pipe/tank/joints	2	Standard pipe and tank material	3	Repair/Replace
BATTERY	Lead-Acid	Acid leakage	Sparks/ignition failure	5	Poor cooling	1	Periodic checking	8	Regular battery checking
TYRES	Rims	Deflation	Inability to drive	6	Less air pressure in tiers and piercing by foreign objects	7	Air pressure matches the tyre specification and hosier tyre	2	Repair/Replace

IX. CONCLUSION

The defining and desired characteristics of each sub assembly were carefully analysed and designed to achieve the ideal characteristics.

CATIA and ANSYS software packages were extensively utilized to model every aspect of the vehicle and also to design and test innovation ideas.

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