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Design of Transmission system for an Electric Go Kart

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Abstract: Traditional go kart has the same components as an electric go kart but the major change is the engine. As in the electric go kart we replace it by a battery and a motor, the main difference now is in the transmission system. This paper will take the practical approach about how to decide your chain, sprocket ratios and all the motor specifications required to maximise the output speed of an electric go kart. This paper will take both the approaches about how to determine your motor from top speed required to the tire size and also the approach where you already have a motor. Electric go karts are the future and this paper focuses on how to build a transmission system for future racing go karts and what parameters are to be considered.

Keywords: Go kart, transmission, gear ratio, sprocket, calculation, electric vehicles.
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I. INTRODUCTION

A transmission system is a system that actually transfers energy from the engine to the tires. But in an electric go kart it changes a bit. The transmission system of an electric go kart has the following parts a battery, a motor, two sprockets, a chain and the axle. This paper helps you to decide the proper distance to be kept between the motor and the axle, the gear ratios to be considered for optimum speed, the motor selection and the calculation of torque and force from the motor to the tires. The design of the sprockets are done on the SOLIDWORKS and also an online tool is used for the determination of the centre distance, also OPTIMUM LAP software is used for virtual results of the go kart in a drag race. The transmission of an electric go kart should be designed in such a way that if there are no changes in gear ratios then it should be selected in such a way that it helps the kart to clear the corners well and also complete the drag race in efficient time.

II. OBJECTIVE

The main objective of this paper is to encourage the students in pollution free battery operated system of an electric go kart and make them aware of the main difference in the transmission system and all the required calculations for the same. The designs of sprockets that are done on the SOLIDWORKS are included with calculations and the analysis of the system on the OPTIMUM LAP software is also included.

1) To determine the motor
2) To determine gear ratios
3) Design of sprockets
4) All the required calculations

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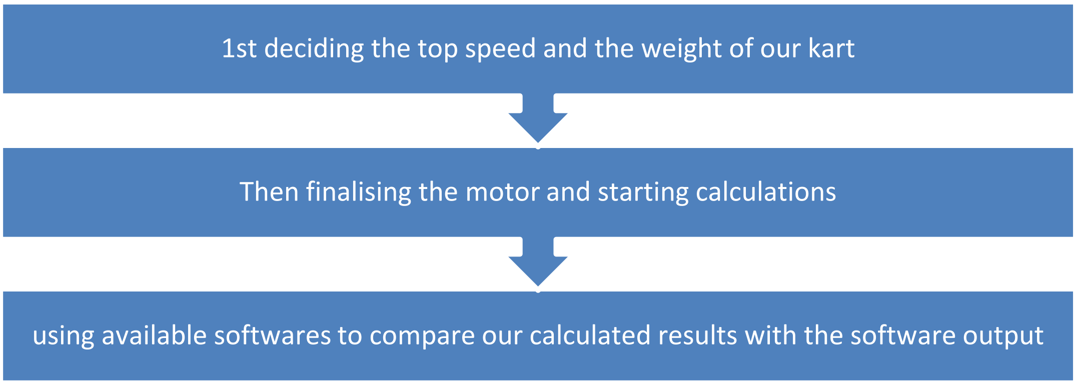
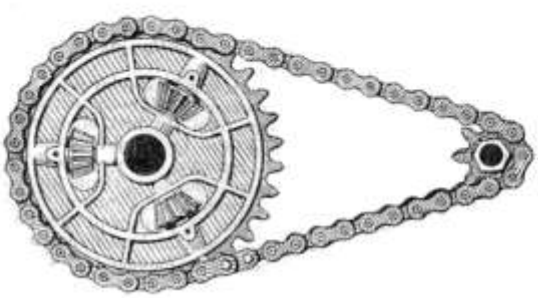
III. METHODOLOGY

The chart below shows how the paper proceeds with the solution for all the problems related to the transmission calculations of an electric go kart



IV. ELECTRIC POWER HOUSE

The design of an electric go kart's power house is very simple. It consists of a motor, motor controller and the chain drive system so finalizing the motor is the 1st part.



After comparison between two 3kW Motors we can confirm the best motor for the go kart

1. Mechatronic trading 3kW BLDC Motor
   - Weight : 14 kg
   - Rated Torque : 9.6 Nm
   - Max Torque : 38.4 Nm for 2 seconds
   - Rated speed : 3000 RPM
   - Max speed : 4000 RPM
   - Peak current : 100 A

2. Compage Automations Systems 3kW BLDC Motor

   Weight : 12.5 kg
   Rated Torque : 9.5 Nm
   Max Torque : 28 Nm for 10 seconds
   Rated speed : 3000 RPM
   Max speed : 3500 RPM
   Peak current : 112.5 A

Depending on the weight to power ratios of both the motors the 2nd motor from Compage Automation Systems is more powerful compared to its weight. Continuing calculations depending on the values of the 2nd motor.

The design of the chain sprocket should be considered by taking the top speed and the weight of the kart. Once the gear ratios are fixed in the calculations, we can find the optimum distance between the motor and the axle sprocket also we can find the number of chain links that has to be in a chain for proper functioning of the transmission system. Both the sprockets can be designed on SOLIDWORKS and can be manufactured in a CNC machine. The material used to manufacture sprockets should be of a very tough material.

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V. CALCULATIONS

❖ Motor to Gear Ratio

After deciding the motor we have the required torque values. Now if we determine the top speed required by the kart we can find the gear ratio. Considering the top speed to be 61 km/hr or 16.96 m/s and the mass as 160 kg

We have the formula G.R. (gear ratio) = $\frac{RPM \times \pi \times tire\ radius}{60 \times speed} = \frac{3000 \times \pi \times 0.270}{60 \times 16.96}$ = 2.5

This is the simplest method to determine the gear ratio if the motor specifications are known but if the motor has to be decided then this lengthy process has to be followed.

❖ Tires to Gear Ratio

1) The first part is to find the total power required to move the vehicle and achieve the maximum speed required
Cr is rolling resistance coefficient, Cd is coefficient of drag, v is the velocity, A is the frontal area

- Rolling resistance force (Fr) = Cr×m×g = 0.01×160×9.81 = 15.696 N
- Air resistance force (Fd) = Cd×0.5×d×v^2×A = 0.8×0.5×1.2×16.96^2×1.174 = 162.17 N
- Gradient resistance force (Fg) = m×g× $\sin\theta$ = 0 (since the angle in which the kart is running is flat and has no elevation)

Now total power is calculated by

- Power required for rolling resistance (Pr) = Fr × v = 15.696 ×16.96 = 266.2 W
- Power required for drag (Pd) = Fd × v = 162.17×16.96 = 2750.4 W
- Power required for gradient force (Pg) = Fg × v = 0
- Total power = Pr + Pd + Pg = 266.2 + 2750.4 + 0 = 3016.6 W

So the selected motor should provide us a power of around 3000W to reach a speed of 16.96 m/s if the weight is considered as 160 kg.

2) To find the required RPM

RPM = $\frac{speed \times 60}{linear\ wheel\ travel (2\pi r)} = \frac{16.96 \times 60}{2 \times \pi \times 0.270}$ = 599.83 RPM

This is the required RPM at the wheel,so the RPM required at the axle is (599.83 × 2) = 1199.66 RPM
Now to decide the gear ratio,as the motor with 3kW power has the RPM of 3000,after dividing the motor RPM with the axle RPM the gear ratio is $\frac{3000}{1199.66}$ = 2.5

3) To find the torque required

The total force calculated is Fr + Fd + Fg = 15.696 + 162.17 = 177.86 N
This force is now divided into 2 equal parts as the axle rod divides the torque into both the rear tires

Force on 1 tire = $\frac{177.86}{2}$ = 88.93 N
Torque on 1 tire = F × r = 88.93× 0.270 = 24.011 Nm
Therefore total torque required on Axle is 24.011× 2 = 48.02 Nm

Dividing it by the gear ratio 2.5 we get 19.209 Nm.This is the maximum torque required by the motor to move the kart.
As the power and RPM are known, the torque could be calculated.

T = $\frac{P \times 60}{2\pi \times RPM} = \frac{3000 \times 60}{2\pi \times 3000}$ = 9.54 Nm.This is the nominal torque of the motor.

By calculating and considering the values as per the electric kart we can choose the best motor and decide the gear ratio required but the weight and the maximum speed should be decided first.

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❖ Acceleration, speed and time calculations

Now since the motor and the gear ratios are decide we can complete the calculation from engine to the tire in this manner

- Nominal condition

The nominal torque is 9.5 Nm. so not considering the maximum condition for now ,the motor is providing 9.5 Nm of torque which will be multiplied by the gear ratio of 2.5 and the axle will be provided with a torque of 9.5 × 2.5 = 23.75 Nm . Now the axle will divide this torque in to two parts , so the torque on a single tire will be $\frac{23.75}{2}$ =11.875 Nm . The total force produced by the both tires will be 23.75 ÷ 0.270 = 87.96 N

- Maximum condition

If the maximum condition is considered for the 1st 10 seconds then the torque changes to 28 Nm and the Torque on axle will be 28 × 2.5 = 70 Nm. this will be divided by the axle and the torque and on a single wheel will be 35 Nm. The total force produced by both the tires will be 70 ÷ 0.270 = 259.25 Nm

Now taking the selected motor and calculating the time required to reach the top speed and also the time required to complete 100 meters and 400 meters of a race track.

Gear ratio = 2.5 , top speed = 16.96 m/s
So at the initial condition for 1st 10 seconds motor gives a torque of 28 Nm
Torque at axle as calculated above will be 70 Nm and the force is 259.259 N
Therefore , acceleration (a) = $\frac{force}{mass} = \frac{259.259}{160}$ = 1.62 m/s^2

Now using kinematic equations speed and distance covered in 1st 10 seconds will be
v = u + at ; v = 0 + 1.62 × 10 ; v = 16.2 m/s
s = ut + $\frac{1}{2}$ at^2 ; s = 0 + $\frac{1}{2}$× 1.62 ×10^2 ; s = 81 m

After 10 seconds , the nominal condition of motor starts
Motor gives a torque of 9.5 Nm and torque at axle will be as calculated before 23.75 Nm and the force is 87.96 N
Therefore , acceleration (a) = $\frac{force}{mass} = \frac{87.96}{160}$ = 0.55 m/s^2

Now using the kinematic equations to find the time required to reach the top speed and time to complete 100 meters and 400 meters as original drag race is of $\frac{1}{4}$ of a mile
v = u + at ; 16.96 = 16.2 + 0.55 × t ; t = 1.38 seconds , but adding the initial 10 seconds the final time will be
t = 1.38 + 10 = 11.38 seconds . So time required to reach the maximum speed is 11.38 seconds

For 100 metres (acceleration will be zero once top speed is achieved)
s = ut + $\frac{1}{2} \times at^2$; 100-81 = 16.96×t+ 0 ; t = 1.12 seconds
Adding the initial 10 seconds we have t = 10 + 1.12 = 11.12 seconds to complete 100 metres

For 400 metres (acceleration will be zero once top speed is achieved)
s = ut + $\frac{1}{2} \times at^2$; 400-81 = 16.96 × t + 0 ; t = 18.80 seconds
Adding the initial 10 seconds we have t = 10 + 18.80 = 28.80 seconds to complete 400 metres

Also the no slip condition of our kart can be checked by the below formula
TE is the tractive force and φ is the adhesion coefficient

TE(max) = φ×Wr = 0.7 × 160 × 9.81 = 1098.72 N

$$TE = \frac{Et \times overall\ efficiency \times gear\ ratio \times drive\ ratio}{R} = \frac{28 \times 0.88 \times 2.5 \times 1}{0.270} = 228.14\ N$$

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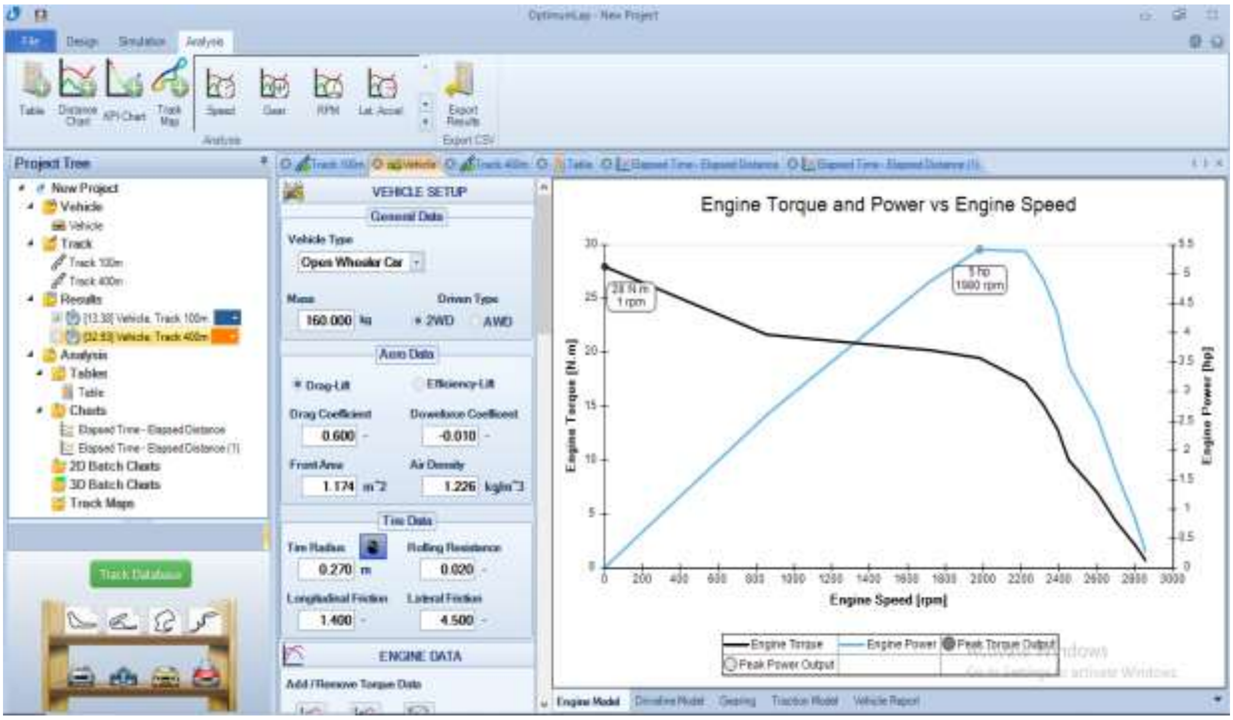
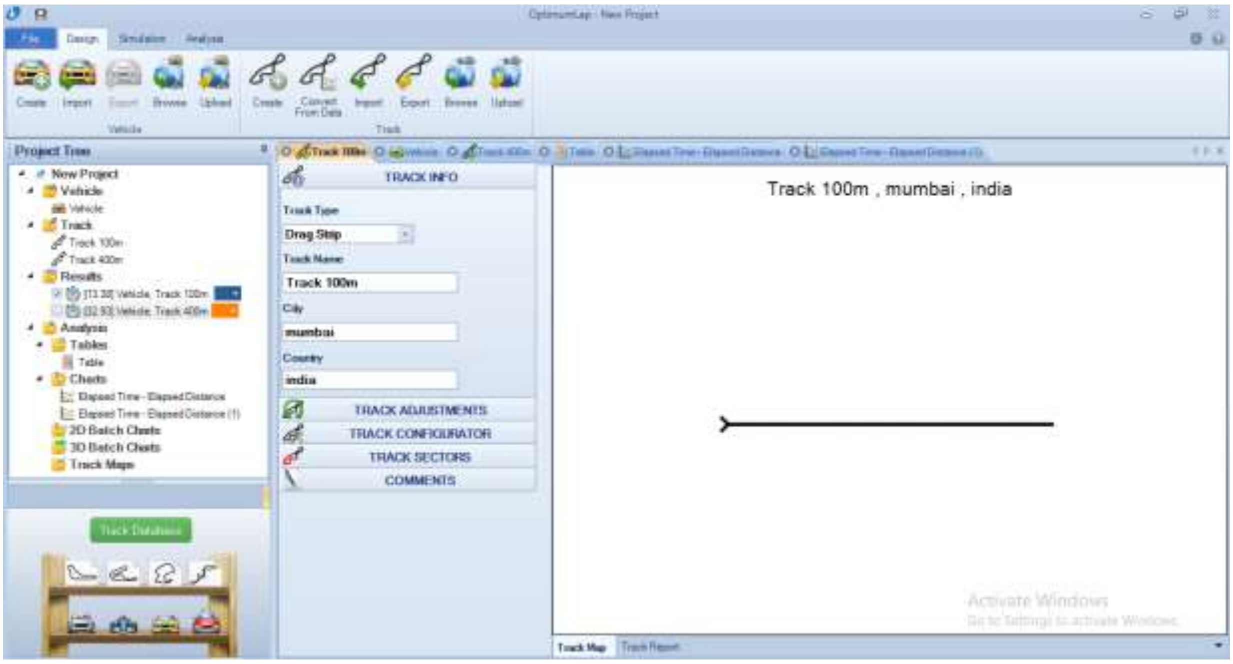
Since TE(max) ≥ TE there will be no slip in the vehicle .

All this is also showed in the graph and values from the OPTIMUM LAP software



Motor Torque Graph



100 metres drag strip

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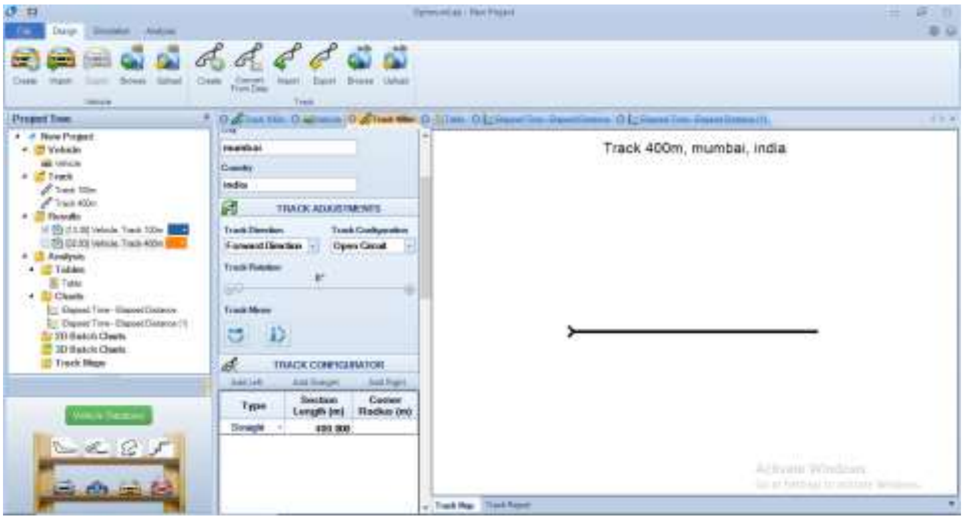
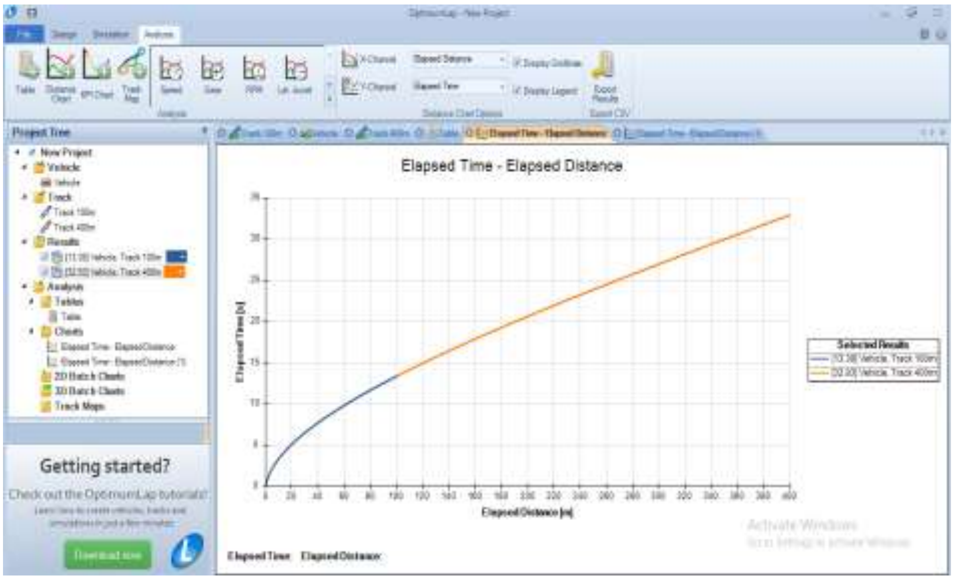
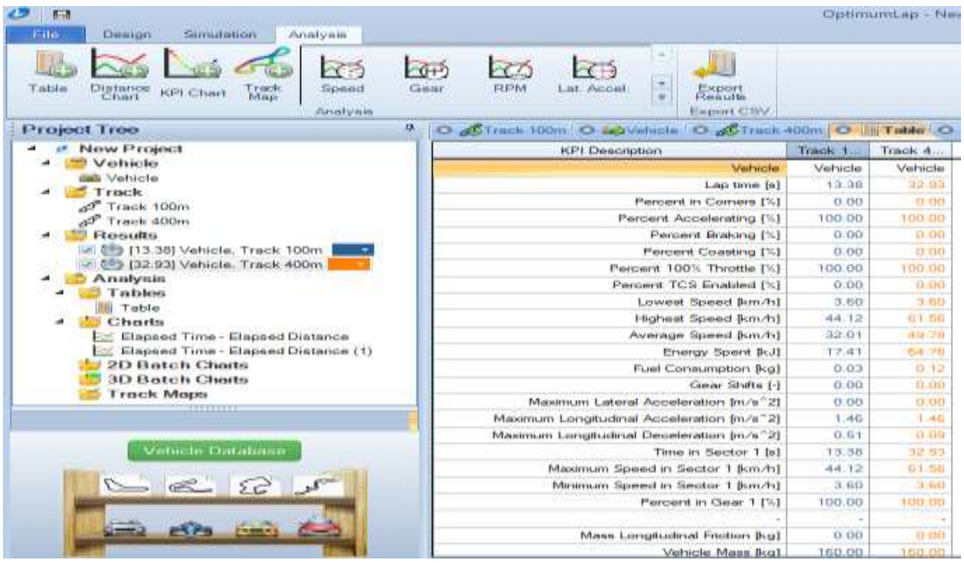


400 metres drag strip



Time v/s Distance graph



Detailed information about the kart running on both the tracks

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From the analysis results on the OPTIMUM LAP software, the results are almost equal as calculated above

Calculated time for 100 m = 11.12 sec From software analysis = 13.38 sec
Calculated time for 400 m = 28.80 sec From software analysis = 32.93 sec

The difference in time is due to the varying motor torque in the 1st 10 seconds when it is maximum
For analysis purpose the data sheet of the motor is entered in the engine data but for calculation purpose the maximum torque is considered as 28 Nm for 1st 10 seconds.

- Calculation and design of Chain and Sprockets

The gear ratio decided is 2.5 and the chain to be used is 520 Chain

- Pitch (p) = 15.88 mm
- Roller width = 6.35 mm
- Roller diameter (d1) = 10.16 mm

Let the number of teeth on Motor sprocket be z1 = 14
Therefore number of teeth on axle sprocket should be 14 × 2.5 = 35

- Diameter of z1 = D1 = $\frac{p}{\sin\frac{180}{z}} = \frac{15.88}{\sin\frac{180}{14}}$ = 71.36 mm
- Diameter of z2 = D2 = $\frac{p}{\sin\frac{180}{z}} = \frac{15.88}{\sin\frac{180}{35}}$ = 177.15 mm

Optimum centre distance will be = 71.6 + 177.15 = 248.75/2 = 124.375 mm = a

- Now centre distance should be between a + 30 and a + 50
- 154 mm ≤ centre distance ≤ 204 mm
- Considering two possible cases of centre distance 170 mm and 203 mm

Now chain length can be calculated by using formula

- $l(p) = 2\times a(p) + \frac{z1+z2}{2} + \frac{{\left. z2-z1 \middle/ 2\pi \right.}^{2}}{a(p)}$
- $a(p) = \frac{centre\ distance}{pitch}$
- Length of chain (l) = l(p) × p
- Chain length for 170 mm as centre distance = 747 mm
- Chain length for 203 mm as centre distance = 808.93 mm

All the above calculated values can be confirmed using an online tool box, pictures of which are given below

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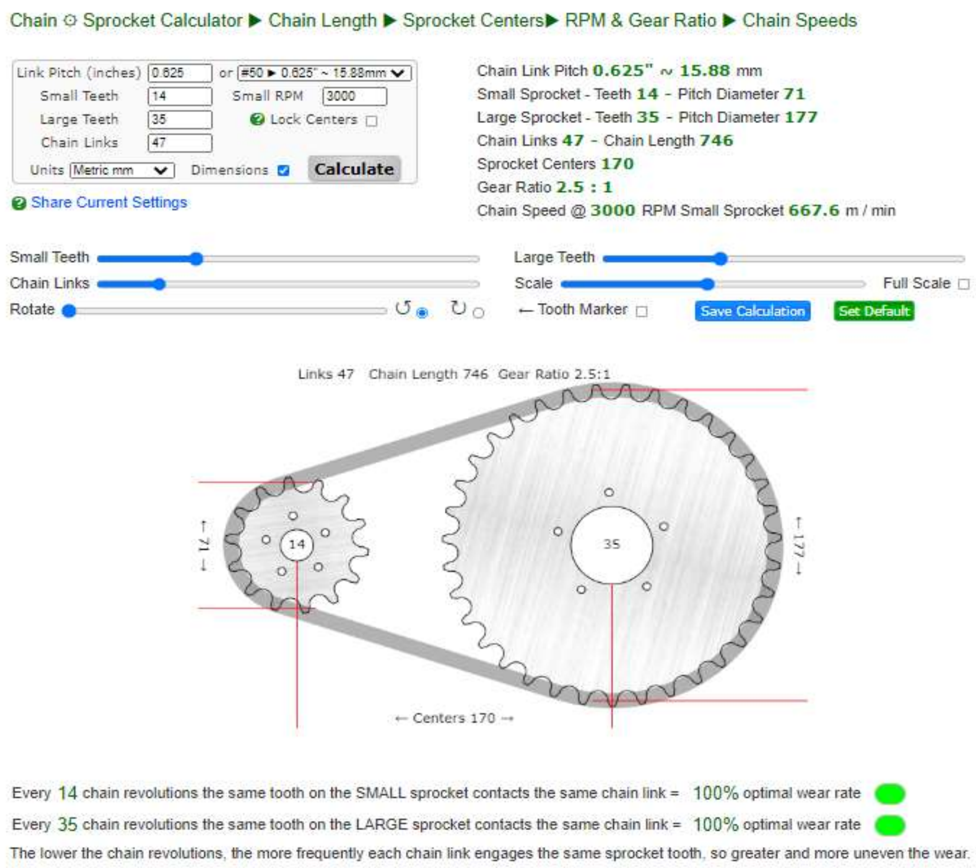
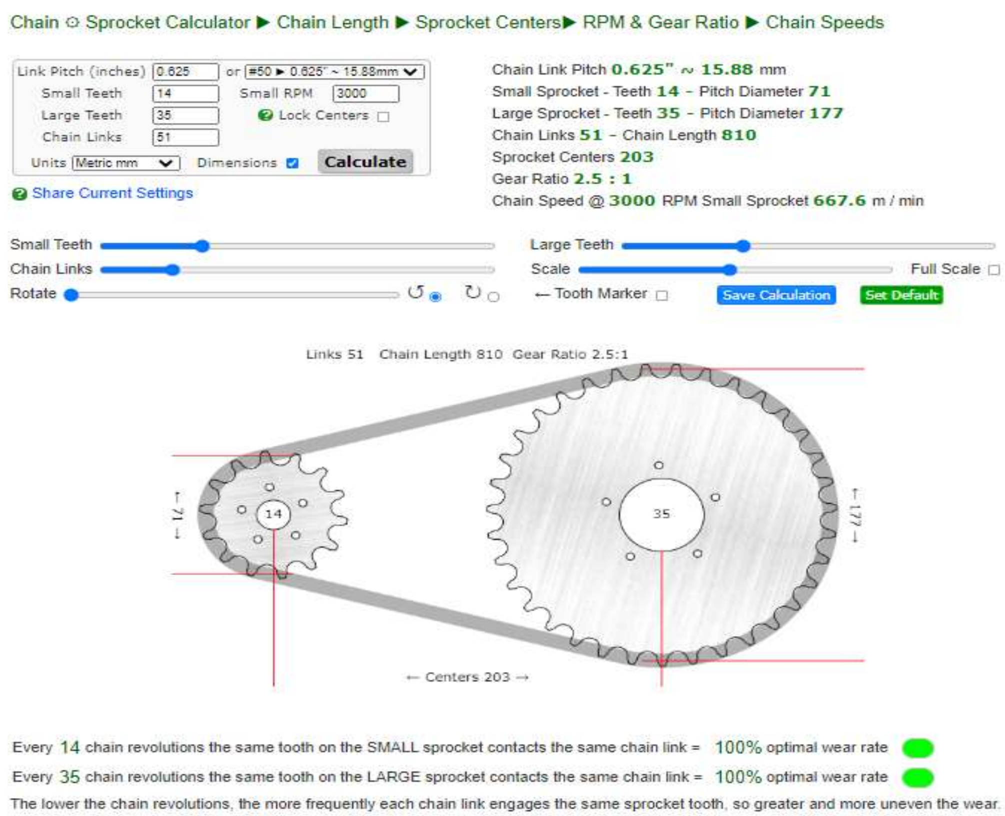


When centre distance is taken as 170 mm



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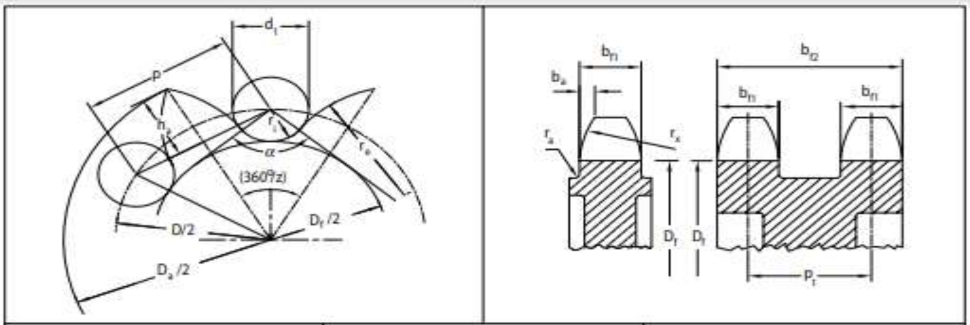
When centre distance is 203 mm

With the help of the following table the calculation of all the required values to design both the sprockets on SOLIDWORKS can be found.



Dimension	Notation	Equation
1. Chain pitch	p	(Table 14.3)
2. Pitch circle diameter	D	$D = \frac{p}{\sin\left(\frac{180°}{z}\right)}$
3. Roller diameter	d_1	(Table 14.3)
4. Width between inner plates	b_1	(Table 14.3)
5. Transverse pitch	p_t	(Table 14.3)
6. Top diameter	D_a	$(D_a)_{max} = D + 1.25\,p - d_1$ $(D_a)_{min} = D + p\left(1 - \frac{1.6}{z}\right) - d_1$
7. Root diameter	D_f	$D_f = D - 2\,r_i$
8. Roller seating radius	r_i	$(r_i)_{max} = (0.505\,d_1 + 0.069\sqrt[3]{d_1})$ $(r_i)_{min} = 0.505 d_1$
9. Tooth flank radius	r_e	$(r_e)_{max} = 0.008 d_1\,(z^2 + 180)$ $(r_e)_{min} = 0.12 d_1\,(z + 2)$
10. Roller seating angle	α	$\alpha_{min} = \left[120 - \frac{90}{z}\right]$ $\alpha_{max} = \left[140 - \frac{90}{z}\right]$
11. Tooth height above the pitch polygon	h_a	$(h_a)_{max} = 0.625p - 0.5d_1 + \frac{0.8p}{z}$ $(h_a)_{min} = 0.5(p - d_1)$

The required value d1 (roller diameter) is taken as 10.16 mm for 520 Chain.

Using all the above formulae we design the motor sprocket as

- D = 71.36 mm
- D(a) = 75.26 mm ≤ x ≤ 81.05 mm
- r(i) = 5.13 mm ≤ x ≤ 5.28 mm
- r(e) = 19.5 mm ≤ x ≤ 30.56 mm
- α = 113.57 mm ≤ x ≤ 133 mm
- h(a) = 2.86 mm ≤ x ≤ 5.75 mm

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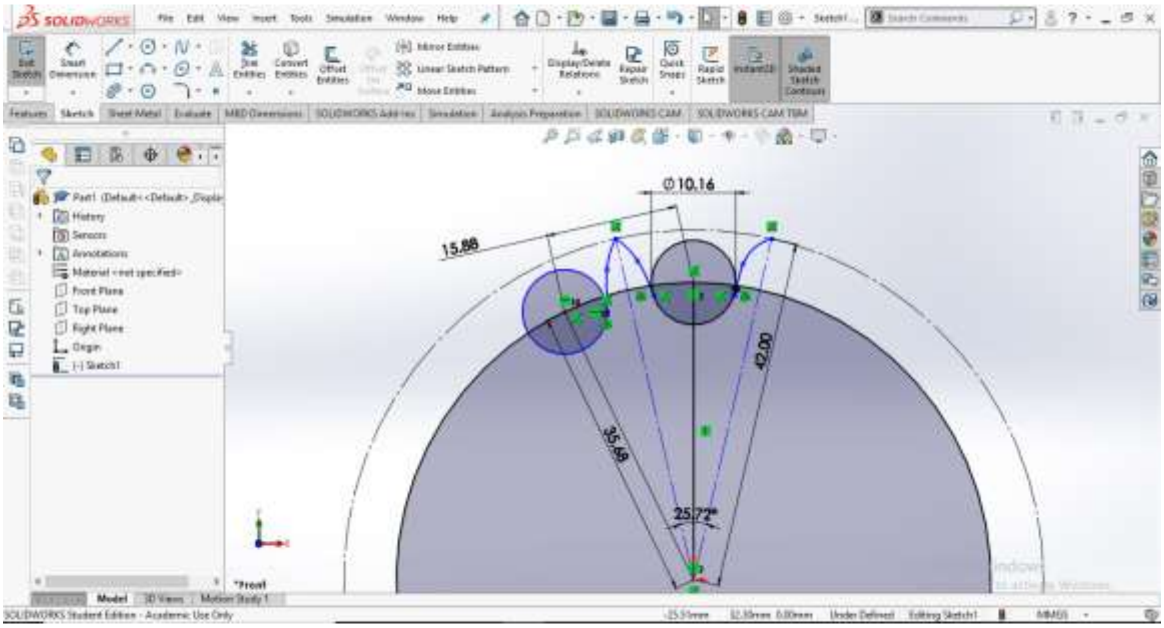
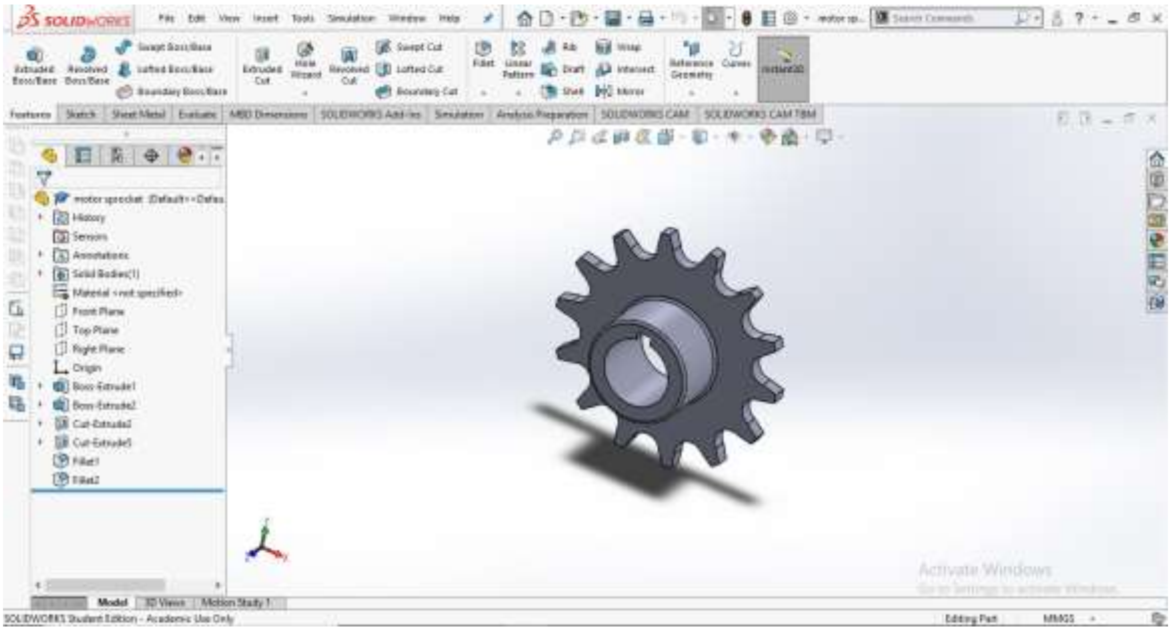


Sketch of motor sprocket



Model of motor sprocket on SOLIDWORKS

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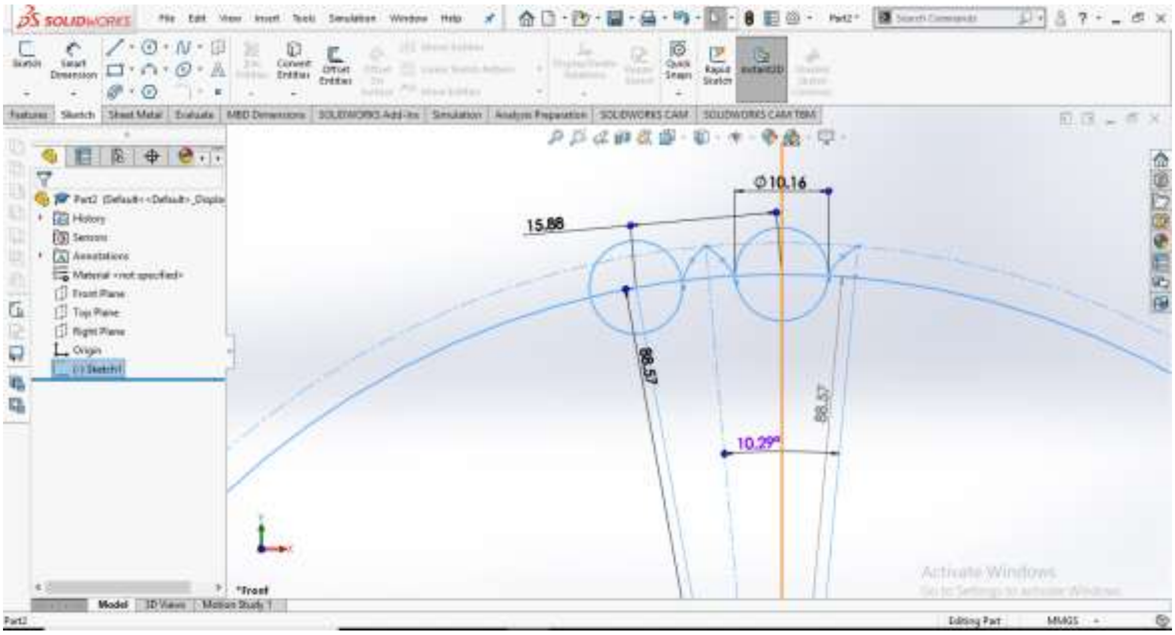
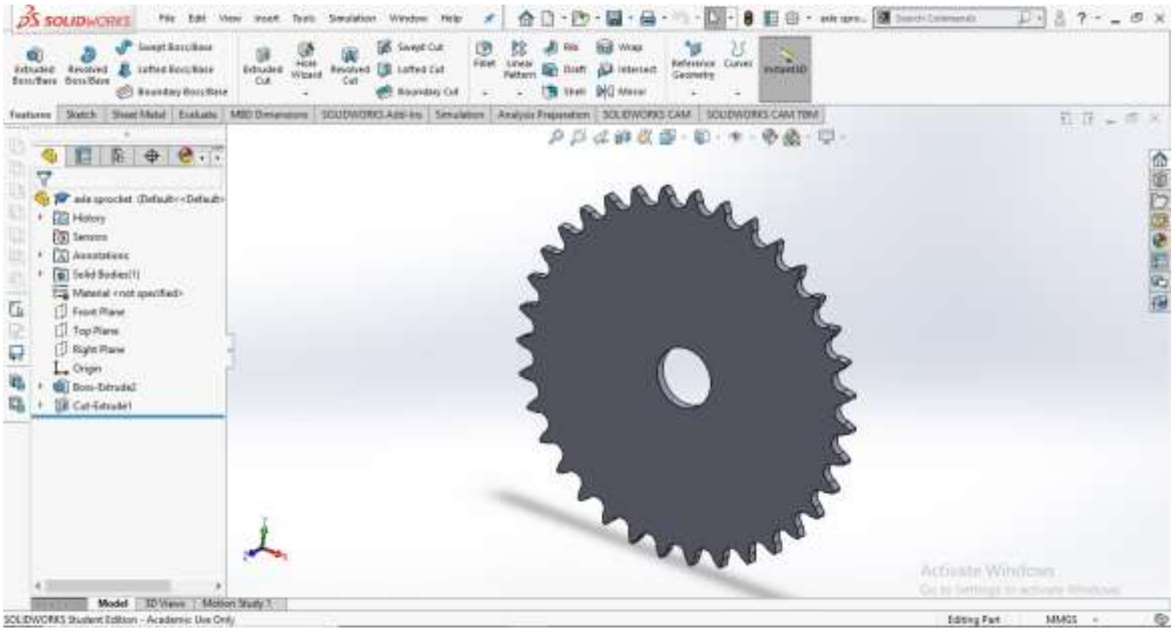
In the same way , design of the axle sprocket.



Sketch of axle sprocket



Model of axle sprocket on SOLIDWORK

VI. CONCLUSION

The paper concentrated on the core part of calculating and designing the transmission system of a single gear electric go kart. All the mathematical formulae were either approach based or from the design data book. Almost every calculation was covered and also how to select motor was discussed. The chain drive system was explained in detail and all the forces and torque required were calculated with some assumptions. The analysis was done on the OPTIMUM LAP software for speed v/s time and the sprocket analysis was done on the online tool BLOCKLAYER and finally the sprockets were designed on the SOLIDWORKS software.

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VII. Future Scope

As electric vehicles are the future the calculation will get more complex as the differential system for the electric vehicles will improve. Batteries can be charged using solar cells and the battery storage systems will be improved in the near future. The basic calculations were covered in this paper but it will change as the motors will become more powerful with higher torque.

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BIOGRAPHY

I am a final year Mechanical Engineering student , headed the transmission department of our college's team Electro Infinity which builds electric go kart for national level competitions such as N.E.K.C.
Our team won the best innovation award 2020 at the N.E.K.C. 2020 Bhopal and I had written this paper to share my work on the transmission system of electric vehicles.