Design of efficient powertrain system for a motorsports race car using a bike engine.

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Abstract. The design of the transmission system for a formula styled racecar using a stock bike engine is one of the best choice for all the engineering students who design the motorsport vehicles for all the student race car build competitions. As there are many rules and restrictions on engine usage such as capacity, Maximum power allowed, type of fuel usage permitted and many more. In addition, this report emphasize on the suitable type of transmission system, differential and drivetrain assembly. The present report shows the various considerations, calculations, analysis and various parametric data’s of stock KTM 390 Engine and the drivetrain of the car.

1. Introduction

As this report is produced as a post design and analysis report of a student racing car designed for a motorsports competition organized by Fraternity of Mechanical and Automotive Engineers [1], the report shows the various components and their specifications and also the various analysis they gone through.

Whenever a race car is to be built, there are many department and sub departments works relative to each other in order to make the car better by increasing its performance, increasing its stability, increasing its controls, increasing the safety, decreasing the loses[3]. In order to make sure the vehicle is perfect many tests and analysis are conducted in each individual sections [2].

To design the components, sub-assemblies and assembly the design software’s NX CAD and SOLID WORKS are used, and to analyses the components against mechanical forces[7] ANSYS software is used, and the vehicle performance analysis[4] software OPTIMUM G is used to analyze the vehicle behavior at different gears[3], at different road conditions and against different race tracks.

The proper evolution of virtual design [9] to actual model, results in a successful car build with the parameters matching the requisites, the issues that are showed up during the development phase are addressed properly with proper analysis. The assumptions and the natural parameters, which are considered during the analysis, are too precise in order to make sure the analysis results are proper and matches with reality.
2. Engine and Powertrain

2.1 Selection of engine for the car.
As per the standard rules of the competition, the engine used to power the car must be a four-stroke primary heat cycle piston engine with a displacement not exceeding 710 cc per cycle. If more than one engine is used, the total displacement cannot exceed 710 cc and the air for all engines must pass through a single air intake restrictor.
For engine selection the multiple available options are the two wheeler motorcycle engines like KTM 390, CBR 600, Royal Enfield 350 etc. as per the ease of availability and affordability KTM 390 engine with a water cooled radiator system was our best choice, as its parameters are within the limit of the rules it is a suitable piece of power source with a considerable power output of 32KW/ 43.5HP @ 9500 RPM

2.2 Selection of gear reduction system
As the car build uses the stock KTM 390 engine with its stock six speed gear box, Majority of the gear ratios were pre designed as per the requirements of the companies’ bike performance. To get the required torque at required speed the only option is to go for the secondary gear reduction.
There are multiple mechanisms available for secondary reduction like Belt and pulley drive, direct mesh gear system, CVT, Chain drive etc. By looking into the force considerations in the transmission, system the chain drive is the more efficient and suitable mode of reduction and the cost of the system is comparatively low as there are few components involved in the chain drive i.e. Driver sprocket, driven sprocket and a chain.
In addition, as the car required using a differential in order to distribute the powers properly among the two rear wheels, the chain driven limited slip differential is used as it meets all the performance and dimensional design specifications.

![Figure 1. Engine Power vs. Engine speed plot stock of KTM 390](Image)
Table 1. Engine specifications as per the manufacture.

| Make Model | KTM 390 Duke |
|------------|--------------|
| Year       | 2015-16      |
| Engine     | Four stroke, single cylinder |
| Capacity   | 373.4 cc / 22.7 cu-in |
| Bore x Stroke | 89 x 60 mm |
| Comp. Ratio | 12.8:1       |
| Cooling System | Liquid Cooled (Water cooled) |
| Lubrication | Forced oil lubrication with 2 Eaton pumps |
| Induction  | Bosch electronically controlled injection |
| Spark Plug | Bosch VR 5 NE |
| Ignition   | Contactless, controlled, fully electronic ignition system with digital ignition timing adjustment |
| Starting   | Electric     |
| Battery    | FTZ-9, 12V 8Ah, maintenance free |
| Max Power  | 32 kW / 43.5 HP @ 9500 rpm |
| Max Torque | 35.3 Nm / 3.6 kg-m / 26 ft-lb @7000rpm |
| Clutch     | Wet multi-disc clutch |

2.3 Gear ratio calculation.

The Torque and speed are calculated for each gear by considering the primary drive ratio (Gear ratios in stock engine gearbox from the manufacturer) as well as secondary drive ratio (Chain gear reduction).

Primary Drive Ratio = 30:80 = 2.66:1
Secondary Drive Ratio = 3.82:1

Overall gear ratio = Primary drive ratio * secondary drive ratio * Individual gear ratios

The secondary gear ratio is decided by iterative process of calculations with the various values ranging from 3.0:1 to 4.0:1, then the speed and accelerations were almost matching in the range of 3.8:1 to 3.9:1. The second decimal iteration arrived at 3.82:1, as it is the point of requisite.

Table 2. Overall gear ratio

| GEARS | Individual ratios | Overall gear ratio |
|-------|-------------------|--------------------|
| 1st   | 2.6666            | 27.0958            |
| 2nd   | 1.8571            | 18.8704            |
| 3rd   | 1.4211            | 14.4401            |
| 4th   | 1.1428            | 11.6122            |
| 5th   | 0.9565            | 09.7191            |
| 6th   | 0.8400            | 08.5354            |

Table 3. RPM and Torques at different gears

| Gears | RPM   | Torque (Nm) |
|-------|-------|-------------|
| 1st   | 4000  | 26.00       |
| 2nd   | 6000  | 30.50       |
| 3rd   | 8000  | 33.02       |
| 4th   | 10000 | 26.00       |
The Torque value at each individual gear can be obtained by
Torque = Maximum engine torque * Overall gear ratio

| GEARS | Torque (N-m) |
|-------|--------------|
| 1ST   | 704.4908     |
| 2ND   | 575.5472     |
| 3RD   | 476.8121     |
| 4TH   | 301.9172     |
| 5TH   | 242.9775     |
| 6TH   | 213.3850     |

The Rotation per minute can be calculated at each gears by the formula
RPM = Engine rpm / overall ratio

| Engine RPM | Overall ratio | RPM | RPS |
|------------|---------------|-----|-----|
| 4000       | 27.0958       | 147.6243 | 2.4604 |
| 6000       | 18.8704       | 317.9582 | 5.2993 |
| 8000       | 14.4401       | 554.0128 | 9.2335 |
| 10000      | 11.6122       | 861.1633 | 14.3527 |
| 10000 +    | 09.7191       | 1028.9018 | 17.1483 |

The relation below can calculate the force acting at the wheels at each gear, which results in the motion of car.
As per the rule and the traction requirement the wheel of 20-inch diameter is used
Radius of wheel = 10 inch = 0.254 m
Force = Torque/radius of wheel

| GEARS | Torque (N-m) | Radius (m) | Force (N) |
|-------|--------------|------------|-----------|
| 1ST   | 704.4908     | 0.254      | 2773.5858 |
| 2ND   | 575.5472     | 0.254      | 2265.9338 |
| 3RD   | 476.8121     | 0.254      | 1877.2129 |
| 4TH   | 301.9172     | 0.254      | 1188.6503 |
| 5TH   | 242.9775     | 0.254      | 956.6043  |
| 6TH   | 213.3850     | 0.254      | 840.0984  |

Force required overcoming rolling resistance and aerodynamic resistance could be calculated as follows
F (total) = Fr (rolling resistance) + Fa (aerodynamic resistance)
Rolling resistance, Fr = fmg
Where f= co-efficient of rolling resistance = 0.014
Acceleration due to gravity, g = 9.81 m/s^2
Mass of the vehicle, \( m = 300\, \text{kg} \)

Fr = 0.014 * 300 * 9.81
= 41.202 N

Aerodynamic drag force, \( F_{ae} = 0.5 \int C_d A (v + v_n)^2 \)

\( F_{ae} = 0.5 \times 1.2 \times 0.5 \times (33.33)^2 = 333.266 \, \text{N} \)

Total Force required = 41.202 + 333.266
F total = 374.468 N

The acceleration and speed at each gear can be calculated by the following equations

Force available = Force delivered – F total

Acceleration = Force available / Weight

| GEAR | FORCE (N) | FORCE AVAILABLE | ACCELERATION |
|------|-----------|----------------|--------------|
| 1ST  | 2773.5858 | 2399.1178      | 7.9970       |
| 2ND  | 2265.9338 | 1891.4658      | 6.3048       |
| 3RD  | 1877.2129 | 1502.7449      | 5.0091       |
| 4TH  | 1188.6503 | 814.1823       | 2.7139       |
| 5TH  | 956.6043  | 582.1363       | 1.9405       |
| 6TH  | 840.0984  | 465.6304       | 1.5521       |

Speed of the vehicle at each gear is, \( \text{Speed} = \text{RPS} \times 2\pi r \times 3.6 \)

| GEAR | RPS   | SPEED (km/h) |
|------|-------|--------------|
| 1ST  | 2.4604| 14.1358      |
| 2ND  | 5.2993| 30.4463      |
| 3RD  | 9.2335| 53.0496      |
| 4TH  | 14.3527| 82.4612     |
| 5TH  | 17.1483| 98.5228     |
| 6TH  | 19.5265| 112.1865    |

By this calculation, the Maximum speed is 112.18 km/h.

And the Maximum acceleration will be \( 8 \, \text{m/s}^2 \)

3. Vehicle dynamics simulation

Optimum Lap software has been developed with the goal of providing users with an ease to use lap time estimation tool. It can be used to rapidly analyse characteristics of a vehicle on a given track. That will enable one to visually see and interpret the effects of changing vehicle parameters. The car data is entered in the software and the readily available standard track details are obtained from the software cloud.

This utilizes a quasi-steady-state point mass vehicle model with simplistic mathematical data, it has the ability to be accurate due to the combined states that the vehicle can achieve. The vehicle is able to accelerate and corner simultaneously as well as decelerate and corner simultaneously. It calculates the corner speeds, calculate the speed accelerating out of the corners and calculates the distance needed in order to decelerate the car for the corners. As the design is done with the Indian standard atmospheric parameters Buddh international race circuit is more suitable to test the car.
As the theoretical calculation matches with the analyzed data’s, it makes clear that the gear ratio calculations and the assumed parameters are proper and the fabrication is proceeded with the same data’s.

4. Transmission design

4.1 Sprocket design calculation.
By considering the gear ratio 3.82:1 and the stock sprocket of the KTM 390 engine (Driver sprocket) with 15 teeth’s.

The number of teeth’s in Rear sprocket (Driven sprocket) = 3.82 * 15 = 57

The sprocket diameter is calculated with the help of online calculator i.e. front sprocket diameter = 3.006° = 76.35mm
Rear sprocket teeth = 57
Diameter of rear sprocket = 11.34” = 288.036mm
In order to design the teeth profile of the sprocket, chain number 525 is considered with a pitch of 0.625 inches.

![Rear sprocket designed (Left) and machined (Right)](image)

**Figure 8.** Rear sprocket designed (Left) and machined (Right)

4.2 Differential specifications

A differential has two main functions: allowing the driven wheels to rotate at different speeds while applying driving torque. In passenger cars, the most common type is an open differential. In racing cars, it is more common to use a limited slip differential or spool.

For open differentials, the drive torque supplied to the left and right wheel is approximately equal. For limited slip differentials and spools, the wheel drive torque can be unequal. The relationship between the two-wheel drive torques is what distinguishes the types of differentials.

For clutch-pack limited slip differentials, torque can be transferred directly from the differential housing to the side-gears through the clutch pack, thereby bypassing the differential gear set. This allows a difference in the left and right torque and the difference in drive torque is governed by two interrelated factors i.e. the differential clutch and the tires. When there is a torque difference that is insufficient to cause the differential clutch to slip, the tires determine the torque difference based on their slip ratio, the vertical load, camber and slip angle.

As the torque difference grows, there is a point at which the clutch will begin to slip. Once this occurs, the torque difference cannot grow any further as the clutch friction has transitioned from static to dynamic friction.

![Limited slip differential designed (Left) and machined (Right)](image)

**Figure 9.** Limited slip differential designed (Left) and machined (Right).
The assembly of differential with the sprocket is secured with the two bearings on either side of the differential with differential uprights, which are mounted on the main chassis frame.

Figure 10. Differential sprocket assembly (Left) and uprights (Right).

Figure 11. Differential sprocket assembly with uprights mounted on Vehicle chassis.
Royal Enfield 350 chain with the chain number 525 and pitch 0.625 inch is used in order to get a better drive efficiency. In addition, a nylon cylinder is used as ideal wheel to avoid the unwanted vibration and noise and acts as a chain tensioner, which will be of smaller diameter and mounted the chassis frame, which is free to rotate when chain slides on its circumference surface.

| Input                                | Answer               |
|--------------------------------------|----------------------|
| p = Chain Pitch (inches)             | 6.25                 |
| n = Number of Countershift Sprocket Teeth | 15                  |
| N = Number of Rear Sprocket Teeth    | 57                   |
| c = Center to Center of both sprockets (inches) | 10.282              |
| Number of Links **                   | 71.618471E           |
| Chain Length (inches)                | 44.761544E           |
| Sprocket Reduction Ratio             | 3.8                  |
| Calculate # of Links                 |                      |

**Note: If your result is an odd number of links add one link to get an even number.

**Figure 12.** Length and Number of the link of the chain.

**Figure 13.** Complete Powertrain assembly.
5. Conclusion

The Efficient powertrain system is designed virtually using NX CAD and SOLIDWORKS engineering design software’s, performance of the system is analysed using the analysis software OPTIMUM G. And the system is designed by using KTM 390 stock engine with stock primary gearbox with a secondary gear reduction of chain sprocket to meet the requisites in terms of speed, power and acceleration.

As expected, the performance of the actual vehicle is comparable with the performance obtained during the simulation of the mathematical and CAD Model. Which intern make the analysis and tuning of the vehicle easier and it is more compatible to know the expected performance outcome even before starting with the actual model.

In the present design KTM 390 stock engine with maximum power of 32 kW / 43.5 HP @ 9500 rpm, which is designed to power a super sport motorcycle with a mass of 180 Kg is successfully used to power a formula styled open wheel race car with a mass of 300 Kg to approximate maximum speed of 130 km/h with an acceleration of 8 m/s².

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