Design and Analysis of Transmission System of an All Terrain Vehicle

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ABSTRACT: This paper will give you the detail information about the working, design consideration and mathematical analysis of transmission system of an all terrain vehicle. It will also help you in selecting different component of a transmission system for all terrain vehicles. In this paper our main intention is to make you aware of important of transmission system in an all terrain vehicle. Our focus is to design a transmission system which will give optimum power output with minimum maintenance and less cost. This paper will also help you in selecting and differencing between manual transmission and automatic transmission. It will also give you the information about different resistance available to an atv and how to consider these resistance during design of transmission. Our part selection criteria will be based on the availability and reliability of component.

I. INTRODUCTION

Society of Automotive Engineers (SAE) organises many ATV events like BAJA SAE, MEGA ATV etc. which are a challenge for many colleges to design and build an off-road vehicle capable of exceptional performance and customer appeal.The Drive Train Team is responsible for the design of the engine through to the wheels. In order to a design appropriate layout for the transmission system for our ATV we are required to select a suitable gearbox with respect to the given rated engine power, space constraints and the various conditions of terrain provided in the Rulebook of Baja 2015. The engine is a constraint in our design, as SAE allows only the use of a Briggs & Stratton engine. The selection of a suitable transmission system is done by comparing the values of traction available and required to accelerate the vehicle.

The goal of the transmission team is to design a power drive train that can make the ATV liable and competitive in different terrains and tracks. For this project, the team set up 7 seven different objectives that the vehicle must accomplish to get declared as a safe and reliable all-terrain vehicle.

The seven objectives were-

1. Size
2. Weight
3. Cost
4. Drag test
5. Endurance test
6. Hill climb test

For size we decide the required dimensions and space of engine and gearbox. Weight and cost was decided according to the specification of the entire drive system including engine, gearbox, chain &sprocket, rear axle etc.

The drag test will test the pickup acceleration and speed of the vehicle in a dirt or flood track of 100 yards. The endurance test examines the reliability and the strength of the transmission system to run the vehicle of continuous 10 laps of 5.4 kms each. The hill climb test challenge is how far the vehicle can climb in an inclined track.

II. CONCEPT SELECTION

In the second phase, the team has to select a transmission system and the components required to make the vehicle compatible to the selected objectives.

1. Selection of engine

We have used internal combustion engine provided by organizer (SAE) and sponsored by Briggs and Stratton in order to get equal input from engine to all the participating team. This Briggs and Stratton 305cc 1450 Series Industrial/Commercial Horizontal Engine produces 19 N-m Gross Torque to get the job done. Compact overhead valve design runs cooler and cleaner delivering more power, longer than conventional engines, increased fuel efficiency and significantly reduced emissions. This engine has fast fuel delivery for one-pull starts and smooth operation.

- Self-lubricating heavy-duty bearing made of steel-backed Teflon coated bronze to withstand load and reduce wear.
- Dura-Bore cast iron sleeve withstands wear and abuse while providing improved oil control. Fuel shutoff valve makes it easy to shut off fuel for safe transportation.

Fig. 1 Engine of All Terrain Vehicle

2. Selection of gearbox

The team's first concept selected for the drive train was manual transmission. The manual transmission works on a set of gear which on shifting manually by the driver produces different gear ratios.

Advantages & Disadvantages

- Manual transmission can easily be designed with a reverse gear.
- Cost effective
- Drivers can have better control over the vehicle as they can shift gears anytime in different situations
- In manual transmission if the clutch pedal is not properly pressed the vehicle can stall. Also, the presence of a clutch makes the gearbox larger and a bit heavier.

The team's second idea was to use an automatic transmission gearbox. This concept of transmission works on a set of planetary gear system which connects to the engine through a torque convertor. The planetary gear set contains four parts: sun gear, planet gears, planet carrier, and ring gear. By locking one of them, the planetary set can generate four forward and one reverse gear ratios. Normally an automatic transmission system has two planetary gear sets with different sizes of sun gears with their planet gears intermeshed.

The final choice was to use a Continuous Variable Transmission (CVT). A CVT is a pulley system where two pulleys changes size relative to each other to optimise the engine power and to obtain infinite gear ratios without the need of shifting gears. Each pulley has two conical plates facing each other at about 17˚. With the help of a belt the two cones shifts closer and apart result in changing the rpm of the shaft.

The primary advantage of CVT is that it allows the engine to operate at optimal power for varying driving condition. Also, CVT weigh much lighter than the manual gearbox.

A choice of selection had to be done between the automatic and manual transmission. However, the concept of using an automatic or CVT was cancelled due to following reasons-

- The assembly of automatic transmission and the torque convertor would have cost much higher.
- Ample space required for installation.
- Specialized experts needed for tuning of CVT.

After reading many research papers our team came up with 4 different criteria to rank each of the three concepts.

Table 1. Comparison of different types of transmission System

Scale 1-5 5 = Best, 1 = Worst	Weight	Cost	Gear ratio range	Easy installation	Total
Manual	4	3	4	4	3.75
Automatic	3	2	4	3	3.00
CVT	3	2	5	3	3.25

Again in manual transmission we had to select between sequential and 'H' pattern transmission gearbox. The 'H' pattern shifter has a complex design and it consumes more space in the driver's cockpit. So moved by the idea of comfortless for the driver we had to select a sequential gearbox.

A survey was carried out in the market for sequential gearbox to meet the requirement of engine power. We found that both the gearboxes of Mahindra alfa and Piaggio ape have same specification, but Alfa gearbox proves to be more reliable than the later.

Table 2. Gear Ratio Of All Terrain Vehicle

GEAR	FINAL GEAR RATIO	FINAL RPM IN GEAR BOX (N)	SPEED (m/s)
1	31.45	120.82	13.24
2	18.70	203.21	22.42
3	11.40	333.33	36.68
4	7.35	517.00	56.90
R	55.05	69.02	7.0

Drag test

For this test, our team set the goal for the vehicle to achieve its maximum speed in a 100 meter track length from a dead stop.

$x = 100m$, $t = 12$ sec.(say), $u = 0m/s$

$x = u + \frac{1}{2}at^2$

$a = 2x/t^2$……(1)

$a = 2*100/12^2 = 1.38\ m/s^2$.

$v = u + at$

so, v(average) = $2x/t = 2*100/12 = 16.67m/s$.

Hill climb

- Air resistance = 0.5ρAVCd
  where ρ =density of air = 1.29
  A = frontal area = 13.99 m^2
  V = velocity of vehicle
  Cd = co-efficient of vehicle = 0.6

- Rolling resistance = mg x crr
  m = mass of vehicle = 250 kg
  g = acceleration due to gravity = 9.81 m/sec^2
  crr = co-efficient of rolling resistance = 0.15
- Gradient resistance = W*sin(45˚) = 176.77

Table 2: Resistance Calculation for different Gears

GEAR	AIR RESISTANCE	ROLLING RESISTANCE	ACCN.
1	19.97	367.875	6.49
2	33.73	367.875	3.17
3	55.16	367.875	1.22
4	85.59	367.875	0.067
R	9.74	367.875	12.57

III. ASSEMBLY OF ENGINE AND GEARBOX

The fourth stage of the project was the assembly of engine and gearbox to drive maximum power to rear wheels.

As the Briggs and Stratton engine used is an Overhead Valve (OHV) we installed the gearbox below the engine. The gearbox was to be mounted on the L-bracket provided. As the gearbox had to be in the horizontal position relative to the vehicle the L-bracket was welded and the gearbox was bolted in it.

Chain or Belt Drive

Now, to drive the power from the engine to the gearbox we could have either used chain drive or belt drive. After consulting to other BAJA ATV teams, our team concluded to the following result-

- A chain is made of iron whereas the belt is made up of rubber. Thus by using a belt drive will absorb more heat produced in the system.
- But, the rubber has more elasticity that the iron. It expands more when subjected to a tensile load. During the transmission process the belt drive will expand too and simultaneously the arrangement of engine and gearbox need to be changed.
- Moreover, timing belt has more possibility of wearing of its teeth. So we preferred to use chain drive over the belt drive.

Table 3: Calculation table for the chain drive

Specification	Value
Maximum pitch	9.525
No. of teeths	35
Pitch diameter of sprocket	103.25
Roller diameter	5.953
Pin diameter	2.976
Chain width	5.953
Thickness of link plates	1.19
Width between outer plate	8.331
Maximum height of roller link	7.81
Length of roller	5.2
X_{min}	285.75
X_{max}	476.25
Number of chain links	135 & 95
Chain length	1285.87

Fig.2 - Assembly of transmission components

Rear Axle

The gearbox selected was Mahindra alfa while the knuckle and hub were that of Maruti's Wagan R. In order to obtain power transmission from the gearbox to the wheels, both the axles of Maruti's Wagan R and Mahindra alfa were used. These two axles were joined to form one piece by ensuring a connection between with the inner attachment of Mahindra alfa and outer attachment of of Maruti's Wagan R.

As the diameter of Wagan R's rear axle is slightly bigger than that of Alfa's, so the WagonR axle is grooved as male part and the Mahindra Alfa axle is grooved as female part. And both are joined together by welding.

Fig.3 - Rear axle welding

Gear Lever

The gear lever was made of an iron rod and its bottom part was welded with a shifter. Instead of installing the provided circular shifter, we designed a hemispherical one.The shifter was cable operated. The one end of the cable was attached at the bottom of gear lever while the other end was connected to the circular shifter which was physically attached with the gear box. The gear lever we used was for a 4 speed sequential gear box.

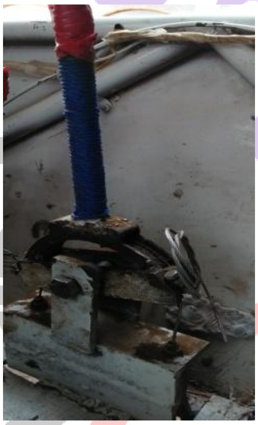

Fig.4- Gear lever

Transmission Pedals

Pedals of clutch & accelerator were installed at the extreme front position so as to reduce the length of the roll cage from front and give that extra length to rear which results in sustaining the center of gravity in the middle of the vehicle.

Because of the design structure of members, the pedal had to be designed in an "L" shape such that the driver's foot could be oriented in a natural position. These pedals need to hold large amount of forces applied by the driver. Both the accelerating and clutch pedals had to be in the same alignment with the brake pedal for the driver comfort. So we designed the pedals taking **mechanical** advantage or pedal ratio of 4:1.

IV. FAILURES AND CHALLENEGES

i. Engine (failure mode – mechanical)

During testing of the vehicle the throttle valve suddenly stopped working. We assumed that the tightening of the governor would be the possible reason. So the engine was bolted out and the governor spring was loosen such that the maximum rpm of engine would not exceed 3700rpm.

ii. Gearbox (failure mode – mechanical)

Due to excessive and improper use of the clutch pedal the clutch failed and stopped working in the mid of endurance test. The clutch plates inside the clutch broke due to heavy friction. The problem was solved my replacing new clutch plates with the old ones.

iii. Chain drive (failure mode – structural)

Misalignment between the output shaft of the engine and the input shaft of the gearbox caused severe damage to the chains and sprocket. This was resolved by ensuring proper alignment between the sprockets and testing it for one hour to see any damage occur.

iv. Rear axle (failure mode – mechanical)

During testing of the vehicle one of the rear axle broke out due to heavy vibration and bending in the axle. It was a serious problem as it could have affect gearbox and wheel rims. Suspension springs were made to adjust and strong and permanent welding was done to ensure the reliability of the axle.

Fig 5. - Front and Rear view of our final ATV.

V. CALCULATION FOR CHAIN DRIVE

1. Maximum pitch = $(900/rpm)^{2/3}$
$=(900/3750)^{2/3}$
$= 0.3861$ inch

In ANSI standard chain dimension matches with pitch 3/8 i.e.0.375 inch.
So pitch of the chain = 0.375 inch =9.525 mm
Smaller the pitch, the less noise, wear and mechanical losses will be experienced.
The chain number would be 35.
As we have to keep same velocity at engine and gear box, so velocity ratio is 1 and no. of teeth on both sprocket would be 35.

2. No. of teeths

From the chart, At 4000 rpm and 10.8 hp power, the number of teeth should be 35. As we have to keep same velocity at engine and gearbox so velocity ratio is 1 and no. of teeth on both sprocket would be 35.

3. Pitch diameter D of sprocket

D = P/sin(180/N)
= 9.525/sin(180/35)
= 106.25 mm

According to ANSI standard chain dimension sprocket thickness = 4.2672 mm

4. Roller diameter (d) = (5/8) * pitch = (5/8) * 9.525 = 5.9531 mm
5. Pin diameter (dp) = (5/16) * pitch = (5/16) * 9.525 = 2.976 mm
6. Chain width (bi) = (5/8) * pitch = (5/8) * 9.525 = 5.9531 mm
7. Thickness of link plates (t) = (1/8) * pitch = (1/8) * 9.525 = 1.19 mm
8. Width between outer plate (bo) = bi + 2t= 5.9531 + 2 *1.19 = 8.331 mm
9. Maximum height of roller link (h) = 0.82 * pitch

=0.82 * 9.525 = 7.81 mm

10. Length of roller (L) = 0.9 bi - 0.15

= 0.9 * 9.525 - 0.15 = 5.2 mm

For best result, the minimum centre distance should be 30 to 50 times the pitch.

11. X_{min} = 30 * 9.525 = 285.75 mm

or

$X_{max} = 50 * 9.525 = 476.25$ mm

12. Number of chain links (k)

$K = (T_1 + T_2)/2 + 2*/P + [(T_2 - T_1)/2\pi]^2 * P/X$

= 135 & 95 links.

13. Chain length (L)

$L = K * P$

= 95 * 9.525 =1285.875 mm

or

L = 135 * 9.525 = 1285.875 mm

The centre distance can also be calculated by

$X = P/4\ [k - (T_1 + T_2)/2 + [\ \{K - (T_1 + T_2)/2\ \}^2 - \{(T_2 - T_1)/2\pi\ \}^2]^{1/2}]$

VI. CONCLUSION

After a lot of research and analysis we concluded to use the manual transmission system for the ATV vehicle, due to its superiority and reliability over CVT transmission. After selecting the type of transmission system we calculated the different types of forces that will act on the gear box, during the different test conducted by us. We also calculated the gear ratio to produce the required amount of torque and to overcome the hurdles. After consideration over many factors and different type of gear box available in market we finalised to use Mahindra Alfa gear box which met all our requirements, and was perfectly fit for our design. Finally after assembly of the transmission system our vehicle worked succesfully and it hit top speed of 45km/hr.

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