Selection, Modification and Analysis of Power Transmission and Braking System of an ATV

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Abstract - This project aims at studying the standard power transmission and braking system and modifying it according to the constraints provided by the Rulebook of Baja Saeindia 2013 to be used in single seater All-Terrain Vehicle. This project includes selection of a suitable transmission system for ATV, according to the given constraints of engine and by analysis of different gearboxes available in the market. The selection of the Braking system is done by analysis of various braking system suitable to the tyre assembly selected.

Index Terms— Transmission system, gearbox, Braking System, Disc brakes.

I. INTRODUCTION

In order to design appropriate layout for the transmission system for our ATV we are required to select a suitable gearbox and modify it, with respect to the given rated engine power, space constraints and the various conditions of terrain provided in the Rulebook of Baja 2013. The selection of a suitable transmission system is done by comparing the values of traction available and required to accelerate the vehicle which are calculated from the gearing ratios of various gearboxes available in the market. Suitable braking system is selected according to the calculated dimensions of tyre and rims. The analysis for the braking system is done by calculation of the total braking torque required and comparing it with the available braking torque.

II. LAYOUT OF TRANSMISSION AND BRAKING SYSTEM

Transmission refers to the entire drive train including gearbox, clutch, differential and axle. It is essentially an arrangement that transmits power from the output shaft of the engine to the wheels. There are 3 major types of transmission layouts, namely:

- Front Wheel Drive
- Rear Wheel Drive
- All Wheel Drive

In front and rear wheel driven vehicles, it is possible that there may be 4 cases:

- Front Engine Front Wheel
- Front Engine Rear Wheel
- Rear Engine Front Wheel
- Rear Engine Rear wheel

The rear engine rear wheel drive was selected because the roll cage of the ATV is such that it has ample space at the rear of the vehicle and also to reduce force on the front axle due to weight of the engine and gearbox.

A braking system is one which stops the motion of a vehicle by converting its kinetic energy into heat energy. There are basically three types of brakes used in automobiles:

- Mechanical Brakes
- Hydraulic Brakes
- Air and other types of Brakes

The Hydraulic Brakes was selected because the fluid exerts equal pressure everywhere; hence the required biasing of the brakes can be achieved at front and rear wheels easily. Also the system is simple in construction and due to absence of joints compared to mechanical brakes has less wear rate.
III. TYPES OF GEARBOXES

Transmission systems may be classified into manual and automatic transmissions. Practical manual Gearboxes comprise of Sequential, Constant mesh or Synchromesh gearboxes. Automatic transmissions include Continuously Variable transmissions (CVT) and Automated manual transmission.

A. Constant Mesh Gearbox

In this type of gearbox, all the gears are in constant mesh with the corresponding gears on the lay shaft. The gears on the main shaft, which is splined, are free. Dog clutches are provided which are free to slide on the main shaft. The gears on the lay shaft are, however, fixed.

B. Synchromesh Gearbox

This type of gearbox is similar to constant mesh type in that all the gears on the main shaft are inconstant mesh with the corresponding gears on the lay shaft are fixed it to it while those on the main shaft are free to rotate on the same. There is a provision of synchromesh device, which avoids the necessity of double-declutching.

C. Sequential Gearbox

A sequential manual transmission is a type of manual transmission where gears are selected in order, and direct access to specific gears is not possible. In this type of transmission system, driver has the ability to select the gear directly before or after the gear currently engaged. A shift lever is provided for shifting of gears.

D. Continuously Variable Transmission (CVT)

Continuously Variable Transmission (CVT) is an automatic transmission that can select any desired drive ratio within its operating range. A simple CVT consists of a metal belt, variable input pulley and variable output pulley. Both the driving as well as the driven pulleys is of variable diameter type. Each pulley is made up of two 20° cones facing each other. A belt is there in the groove between the two cones. The two cones are moved closer or far apart using hydraulic pressure, hydraulic force or spring tension. The two pulleys change their diameter relative to each other and thus infinite number of gear ratios is obtained.

IV. SELECTION OF TRANSMISSION SYSTEM

A choice of selection had to be made between the Manual transmission and CVT. However the incorporation of CVT was cancelled due to the following problems. While reading a research paper ‘A Kinematic analysis and design of continuously variable transmission’ by Christopher Ryan Willis it was learnt that, tuning of CVT requires the person to physically change the available combinations of weights and springs to see which set produces the best performance, which is a tedious job. Also coupling from the engine to the CVT unit would not be readily available and would have to be fabricated.

In manual transmission again a selection had to be made between sequential pattern and the conventional H pattern. However, having a conventional H pattern shifter is too cumbersome in the given restriction of space in the driver’s cabin. The sequential gearbox matches easily with the selected engine and can be coupled without any difficulties. For the given requirements of power to be transmitted, a sequential gearbox was available.

V. BRAKING SYSTEM

The basic function of the brakes is to stop the vehicle in motion within the shortest possible distance, by converting Kinetic energy of the vehicle in to heat energy. The basic types of brakes, which may be used in the ATV, are:

A. Disc Brakes

When the disc brakes are applied hydraulically actuated pistons move the friction pads into contact with the disc, applying equal and opposite forces on the latter. On releasing the brakes, the rubber sealing rings act as return springs and retract the pistons and the friction pads away from the disc.

B. Drum Brakes

When the brakes are applied, brake fluid is forced under pressure from master cylinder to the wheel cylinder which in turn pushes the brake shoes into contact with the inside surface of the drum. When the pressure is released, the return spring pulls the shoes back to their rest positions.
VI. SELECTION OF BRAKING SYSTEM

A choice has to be made whether to choose disc brakes or drum brakes. After studying the advantages and disadvantages of both, Disc brakes have been selected for the ATV for the following reasons:

- Disc is directly in contact with cooling air, thus no separate cooling system for brakes
- Brake pads undergo uniform wear; this is beneficial since ATV requires frequent use of brakes.
- No loss of braking efficiency due to expansion/contraction of Disc
- Total weight of disc-brake arrangement is less than drum-brake arrangement
- Designing of disc brake is simpler

Fig 2: Labelled diagram of Disc Brakes

VII. SELECTION OF ENGINE

The Piaggio Ape Diesel engine was selected as it met with the as it closely matched with the constraints provided in the Baja Saeindia Rulebook 2013. The specifications of the engine are as follows:

Make and Model : Piaggio Ape Diesel Engine (Single Cylinder 400cc)
Clutch : Multiplate Wet type
Maximum Power : 8hp at 3600 rpm
Maximum RPM : 3600
Maximum Torque : 16.7 Nm at 2500 rpm

VIII. ANALYSIS FOR SELECTION OF TRANSMISSION SYSTEM

In order to keep a vehicle in motion, the engine has to develop sufficient power to overcome the opposing road-resistance, which is expressed as tractive resistance or tractive effort. In the process of selection of a suitable gearbox, according to the constraints of power requirement analysis was carried out to calculate traction at various gearing ratios i.e. different speeds of the engine. This traction was compared with the effort required to overcome various resistances offered to a vehicle in motion. The road resistance opposing the motion of the vehicle consists of 3 components

- Roll Resistance (Rr): It is the force resisting the motion when a body (tire) rolls on a surface (road). It is given as:
  \[ Rr = (0.015 + 0.00016v)W \]  
  Where
  \( v \) = Velocity of the vehicle
  \( W \) = Weight of the vehicle
- Air resistance (Ar): Power is needed to counteract the resistance created by the vehicle moving through the air. The air resistance opposing force is directly proportional to the square of the vehicle’s speed.
  \[ Ar = C_d \times \rho \times v^2 \times (A/2) \times 0.1 \]  
  Where
  \( C_d \) = Coefficient of drag = 0.29
  \( \rho \) = Density of air = 1.29kg/m^3
  \( A \) = Frontal area of the vehicle = 3.6027m^2
- Gradient resistance (Rg): Power is required to propel a vehicle and its load up any gradient likely to be encountered.
  \[ Rg = W \times (\sin45°) \]  
  The inclination of the road surface is taken as 45°.

A survey was carried out in the market for Gearboxes to meet the requirements of engine power. Along with Piaggio Ape, it was found that Mahindra Alfa also fulfilled the requirements. The Gearing Ratios of Mahindra Alfa were almost the same as that of Piaggio Ape. However, since the engine to be used was of Piaggio Ape, Piaggio Ape gearbox was selected for ease of coupling from engine to gearbox.
From the above table, it is seen that the traction calculated is greater than the traction required to set the vehicle in motion. Also for a gradient of 45°, the ATV can move in 1st and 2nd gear comfortably.

The braking system was selected based on the braking torque requirements obtained from dynamic load on axles. The outer diameter of tyre was calculated to be of 25 inches (rear) and 22 inches (front). Tyres suitable for the requirement were available in the dimensions 25-7-13 and 22-6-13 for rear and front tyres respectively. According to the torque requirements and rims selected, we selected the Disc Brakes of Maruti Zen.

The changes in axle load during braking depends upon the static laden conditions and deceleration.

Front axle dynamic load is given as \( W_f \):
\[
W_f = w_1 + (\alpha / g) \times W \times (h / L) \tag{4}
\]
Rear axle dynamic load is given as \( W_r \):
\[
W_r = w_2 - (\alpha / g) \times W \times (h / L) \tag{5}
\]

Where
- \( w_1 \) = Static load on the front wheel (each) = 75 kg
- \( w_2 \) = Static load on the rear wheel (each) = 100 kg
- \( \alpha \) = retardation of the vehicle
- \( W \) = Weight of the vehicle = 350 kg
- \( h \) = Distance of C.G from ground = 18" = 0.4572 m
- \( L \) = Wheel Base = 72" = 1.8288 m

Retardation of vehicle was obtained from the minimum stopping distance of vehicle at maximum speed travelling on a flat road. And the minimum stopping distance of the vehicle was calculated using the Work Energy principle. Retardation of the vehicle was found out to be \( \alpha = 6.37 \) m/s². Thus, the value of dynamic load on front and rear axle was found to be 131.89 kg and 39.89 kg respectively.

The braking torque distribution available at the front and rear discs was obtained by using the following formulae:

Torque at each front disc is given as \( (T_f) \):
\[
T_f = W_f \times (f / g) \times R_f \tag{6}
\]
Torque at each rear disc is given as \( (T_r) \):
\[
T_r = W_r \times (f / g) \times R_r \tag{7}
\]

Where
- \( R_f \) = Radius of front tyres = 11" = 0.2794 m
- \( R_r \) = Radius of rear tyres = 12.5" = 0.3175 m
- \( f \) = Deceleration due to braking = 3.96 m/s²
- \( x \) = Distance of C.G from rear axle = 20" = 0.508 m

Deceleration can be calculated using the following formula which is obtained by equating inertia force of the vehicle to the braking force applied.

Thus the total braking torque required was found out to be 196.188 Nm.

While studying a paper 'Brake Force Requirement Study: Driver- Vehicle Braking Performance as a Function of Brake System Design Variables' [4] it was determined that the average braking effort applied by the right foot while applying brakes for a deceleration of 0.75g is about 85lbs i.e. 38.55 kg. However, the maximum deceleration in the vehicle is about 0.4g and hence the maximum braking force required to be applied by the driver would be about 45.77 lbs (20.76 kg). Thus the force applied by the driver to the master cylinder was 203.675 N and the pressure was 0.802 MPa.

The Braking torque available in the system selected was calculated using following formulae and it was found to be greater than the braking torque required.

\[
T = 2 \times \mu \times (P \times A) \times R \times \text{no of disc brakes} \tag{8}
\]

Where
- \( \mu \) = 0.4
- \( P \) = Pressure in the master cylinder
- \( A \) = Area of the caliper of the disc = 4400 mm²
- \( R \) = Effective radius of the disc = 95 mm

X. INNOVATION IN GEAR SHIFTING MECHANISM

A study of the previous design reports pointed out that the sequential gearbox is provided with mechanical
linkages for gear shifting to the driver cabin. It would be more convenient if a provision for gear shifting is mounted on the steering wheel itself, for better control driving experience. It was planned to mount a Bipolar Stepper-Motor on the gear-shifter to provide positive or negative Gear shifting with the help of 2 buttons mounted on steering wheel. Gear shifting will be possible with the help of 2 buttons mounted on steering wheel.

This gear shifting mechanism was selected since it has the following advantages:

a. Easy gear shifting process mounted on the steering wheel
b. Quicker gear shift, thus better overall acceleration
c. Both hands on steering wheel at all times, therefore better handling; especially at turnings and difficult terrain
d. Time taken for changing of gear will reduce considerably (critical in racing conditions or where gear has to be brought down promptly)

Fig 3: Simple Block Diagram of Stepper Motor

The stepper motor was to be mounted on the gear shifter of the gearbox. The torque provided by the motor should be greater than the torque required to shift the gear. Hence, the torque to change the gear using the gear shifter is found. The total moment required for 1 gear shift = 0.2 N-m= 2.02 Kgf-cm

Basic torque characteristics for Stepper Motor:
1) Torque is inversely proportional to rpm
2) For a given Torque value, higher capacity Motor will have more rpm

A 3Kgf-cm capacity stepper motor was decided upon to be used. But a 10Kgf-cm capacity stepper motor with a 1.8° step will be used since it increases the rpm of the motor i.e. the time between gear changing is negligible.

XI. FABRICATION

After the design and selection of components was complete, the next challenge was assembling the parts together. The challenges and obstacles were overcome by modifications and custom made parts. The major modifications carried out which are mentioned and discussed.

The gearbox was to be mounted on the L-bracket welded to the Rear-Roll-Hoop of the ATV. This bracket was at an angle of 17° from the vertical.

The L-bracket had to be in a horizontal position so that the bolts of the gearbox could be mounted on the bracket. In order to achieve this, wedges were placed to the L-bracket and welded to it, to get horizontal planes to mount gearbox holder.

Fig 4: Modifications for Gearbox Mountings

The gearbox selected was Piaggio Ape while the knuckle and hub selected were that of Maruti Zen. In order to obtain power transmission from the gearbox to the wheels, both the axles of Maruti Zen and Piaggio Ape were used. These two axles were joined to form one piece by ensuring a connection between with the inner attachment of Piaggio Ape and outer attachment of Maruti Zen. The two attachments were connected together by a sleeve which accommodates both the axles of different diameter. The sleeve was welded to the shaft in contact, thus acting like a coupling.
Fig 6: Piaggio Ape and Maruti Zen Axle

The gear shifting lever was mounted on the front panel as shown in the figure. The connections were made to the gearbox with the help of linkages and steel cables.

Fig 7: Modifications in Axle i.e inclusion of Sleeve

In conclusion, the Transmission and Braking system were incorporated in the Roll Cage along with other systems of suspension, steering and other essential elements to build an ATV.

XIII. REFERENCES


Fig 7: Gear Shifter

XII. CONCLUSION

A study was made and the power and braking requirements were calculated. On the basis of these requirements and results, a detailed market study was carried out and suitable materials, components and parts were selected. All these components were installed, mounted on the roll cage of the ATV thus completing the fabrication process of the vehicle.