Variation of Gear Ratios of a Vehicle Gearbox which depends upon its type of Engine and Utility

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Abstract – This paper is an analysis and study of gear ratios of Gearbox of different vehicles, their dependency on various factors like vehicle utility, engine, etc. and it also presents a holistic view of the factors which affect vehicle speed calculation and analysis.
Index terms – Engine and gearbox tuning, Petrol v/s Diesel, Close Transmission ratio, Engine Stalling, 4WD

I. INTRODUCTION

Today's era is marching towards the rapid growth of automobile industries. There is a higher demand of Speed and Performance. But along with all that efficiency and fuel consumption is also important.

This Paper gives a detailed study about gear ratios in an automobile gearbox and their relation with Engine Specifications, i.e. Power, Torque, rpm at which maximum power and Torque generate and vehicle utility. Gearboxes are frequently used in an automobile for Power transmission, Because Torque requirement of a vehicle vary with Speed. The main functions of a gear box is as follow:

1. It Provides Torque which is needed to move the vehicle under variety of road and Load conditions. It can be obtain by changing gear ratio between engine crankshaft and vehicle drive wheels.
2. Can shift into Reverse gear so the vehicle can move in backward direction.
3. Can shift into Neutral for rest and starting Position.

It tells why gearbox of a Petrol and Diesel Engine is different for the same car, this is explained by taking an example of Maruti Suzuki Swift. Gearbox used in a sports car is different from a standard car gearbox. In this Study *it is explained why it is needed*? Vehicle Speed analysis and how it depends upon size of tyre, gearbox specifications.

The Paper will you help to know about the reason behind the Parking during uphill and downhill and benefits of 4 Wheel Drive Mode.

II. ENGINE AND GEARBOX TUNING

In I.C Engine Torque and Power varies with engine rpm. I.C engine produces almost zero amount of torque at zero rpm. Initially torque produces by engine increases with rpm up to a maximum value and then further decreases with rpm. Because Torque produce by engine depends upon volumetric efficiency of cylinder, means how much air or mixture is filled in cylinder.

Power of an engine is the function of Torque and rpm. Initially, the power increases with increase in rpm up to a maximum limit and after then it decreases with further increase in rpm. It is because initially with increase in rpm, volumetric efficiency increases and after a limit it decreases with further increase in rpm. At higher rpm, exhaust valve begins to float, their return springs can't reseal the cylinder before the next ignition occurs. Thus the expanding gases leaks out before they can apply full force to the top of the piston and hence Power is lost.

Racing cars have much stiffer return springs for just this reason, so they can operate at higher rpm. But that creates more pressure on the cam and valves, they wear out quickly. Thus, in race car valve train must be rebuilt after a few races.

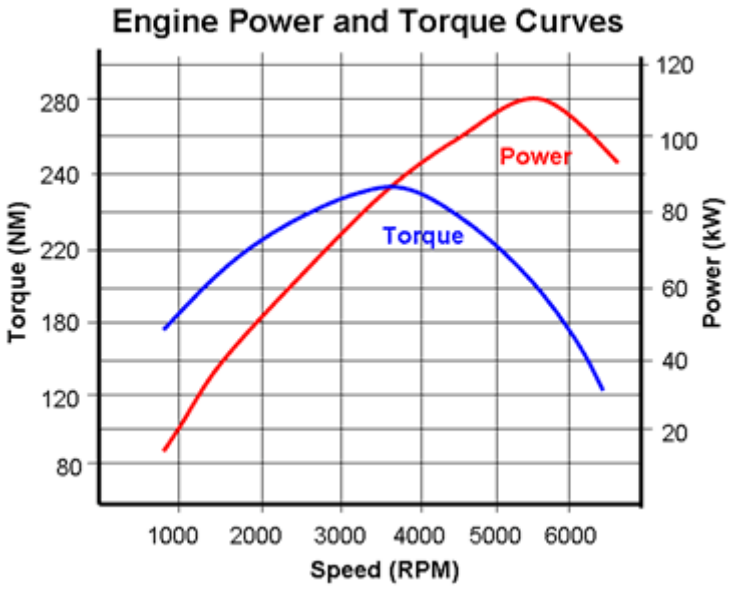

Figure 1: Graph between Engine Power and Torque v/s Speed

This is the graph of a Gasoline engine. The maximum torque produce by engine is at 3500 rpm and maximum Power is at 5500 rpm. It means that the **Engine has a Power band of 3500-5500rpm in which it is most efficient, in terms of power, torque and fuel economy.**

Ideal rpm of an engine is about 800-900 rpm, which is just sufficient to drive the accessories as required viz. water pump, oil pump, alternator, etc. As during starting vehicle needs more torque, so we need to lower gear ratio (1st Gear) to start.

It is the Torque which decides acceleration, higher the torque greater will be acceleration and Power which decides speed, higher the power more will be speed.

During Upshift (to switch from lower to higher gear) rpm of the engine decreases which depends upon change in gear ratio. So for better acceleration and performance, the drop in engine rpm should lie under the power band of that engine. Drop rpm should come near about that rpm at which maximum torque is produced in order to have better acceleration.

Due to this reason, racing cars uses close ratio transmission in which there is not much drop in engine rpm during upshift to keep the car in power band of engine, which is further explain in this.

Let's take an example of Mahindra KUV1oo

Engine specification:

Capacity: 1198cc (Petrol)
No. of cylinders: 3
Max. Power: 81bhp@5500rpm
Max. Torque: 115Nm@3500-3600rpm

Gear Box specifications: 5 Speed Forward Manual

Table 1: KUV 1OO Gearbox Specifications

	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear	Final Drive ratio
Gear ratio	3.909:1	2.100:1	1.481:1	1.094:1	0.838:1	4.235:1

The overall gear ratio of 1st gear is 16.5544 (3.909x4.235). If the upshift is done at 4000 rpm from 1st gear to 2ndgear then after it rpm drops to 2149 rpm. That is probably Ok at this speed. If we shift from 4th gear to 5th gear at 4000 rpm, then the rpm drops to 3064 rpm. This is because at high speed vehicle needs more power to overcome aerodynamic drags and road resistance forces. So, there must a tuning between engine and gearbox.

Design of gearbox also depends upon engine specification. To elaborate this let us take an example of Motorbike.

Hero Splendor pro

Engine specifications

Displacement: 97.2cc
Maximum power: 5.74kw @7500rpm
Maximum torque: 7.54Nm@5000rpm

Gearbox specification:

Table 2: Hero Bike Gear Box Specifications

	Primary reduction	1st Gear	2nd Gear	3rd Gear	4th Gear	Final reduction
Gear ratio	3.722:1	3.182:1	1.706:1	1.238:1	0.958:1	3.071:1

As we can see from this example that there is difference between a car gearbox and motorbike gearbox. In motorbike gearbox an extra gear reduction is given i.e. Primary reduction. As in motor bike to make it compact large engine cannot be use, so a small engine is used in it. In order to Provide require torque to move it, as the torque produce by it is much smaller than a car engine. Generally Primary ratio in a car gearbox is 1:1.
So because of primary reduction speed of gearbox output is reduced, i.e. rpm of gearbox output. To overcome it a large tyre is used to have more speed.
If we compare Passenger and Commercial (Loading) vehicle, Commercial vehicle needs more torque to run than Passenger. Because it carries huge amount of load with it, to run it requires more torque.
Let's take an example Mahindra Alfa Passenger and Alfa PICK UP. It's a three wheel product of Mahindra.

Engine specifications
Displacement: 395cc (diesel)
Max. Power: 5.51kw@3600rpm
Max. Torque: 16.7Nm@2200-2800rpm
Gearbox Specifications

Table 3: Alfa Gear Box Specifications

	Primary reduction	1st Gear	2nd Gear	3rd Gear	4th Gear	Final Reduction
Alfa Passenger	2.869:1	4.6:1	2.733:1	1.677:1	1.115:1	1.938:1
Alfa PICK UP	2.869:1	4.6:1	2.733:1	1.677:1	1.115:1	2.381:1

As from the given example we can say the design of gearbox of any vehicle depend on its utility. Both of they share the same Engine, Alfa PICK UP have lower final drive ratio than passenger. As Alfa PICK UP is a type of commercial vehicle, Hence it requires more torque than a Passenger one. Here in order to increase the torque of alfa pickup the final drive ratio is deducted. while there is too much similarity in both vehicle`s gearbox.

III. GEARBOX OF A DIESEL AND PETROL ENGINE

Torque: It is the measurement of twisting of force, means how hard output shaft can turn.
Power: It is the amount of work that engine can do in unit time.
It is the Torque and Power which makes both Diesel and Petrol engines different from each other.
For the same volume, Petrol engine produces more Power than Diesel engine because it has higher rpm than diesel engine. The stroke distance in petrol engine is lower than Diesel engine and have larger bore than diesel. Diesel engine produces huge amount of torque due to higher calorific value of diesel fuel and have large stroke.
It can be better understand with an example of Maruti Swift.

Table 4: Maruti Suzuki Swift Engine Specification

	Maruti Swift (Petrol)	**Maruti Swift (Diesel)**
Capacity	1197 cc	124811248 cc
Compression ratio	11.0:1	17.6:1
No. of Cylinders	4	4
Max. Power	84.3 PS @6000rpm	75 PS @4000rpm
Max. Torque	115 Nm @4000rpm	190 Nm @2000rpm

But the Torque requirement for a car to run should be same whether it is Diesel or Petrol. So in order to provide same amount of torque to car, the overall gear ratios of Petrol is lower than Diesel engine car. Let us take an example of Gear box gear ratio of Maruti Suzuki Swift Petrol and Diesel.

Table 5: Swift Gear Box Specification

	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear	Final Drive Ratio
Petrol	3.545	1.904	1.280	0.914	0.757	4.388
Diesel	3.545	1.904	1.233	0.911	0.725	3.940

It is clear from above, that Petrol engine car have lower gear ratio than Diesel. Because Petrol engine produces less torque than diesel engine, so to provide require amount of torque, it has different Gear box.
It can be make more clear with another example of Mahindra KUV 1oo.

Table 6: Mahindra KUV 1OO Engine Specifications

	Mahindra KUV 1oo (P)	**Mahindra KUV 1oo (D)**
Capacity	1198 cc	1198 cc

No. of Cylinder	3	3
Max. Power	81 bhp@5500 rpm	77 bhp@3750 rpm
Max. Torque	115 Nm @ 3500-3600 rpm	190 Nm @ 1750-2250 rpm

Transmission

Table 7: Mahindra KUV 1OO Gear Box Specifications

	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear	Final drive ratio
Petrol	3.909:1	2.100:1	1.481:1	1.094:1	0.838:1	4.235:1
Diesel	3.909:1	2.100:1	1.481:1	1.094:1	0.838:1	3.611:1

Now we calculate overall gear ratio of both Petrol and Diesel.
The overall gear ratio in 1st gear is 16.554 for Petrol and 14.115 for Diesel. In 1stgear max. torque transfer to wheels is 2681 Nm in Diesel and 1950 Nm in Petrol.

IV. CLOSE TRANSMISSION RATIO

A **close-ratio transmission** is a vehicle transmission in which the difference between the gear ratios of the gears is minimized relative to other transmissions used in similar vehicles. The basic need of Close ratio is good for racing to minimize RPM drop between gears to keep engine in optimum hp range.
CRT offered in sports car in which the engine is turned for maximum power in narrow range of operating speed.
Let us take an example of BMW323i

Table 8: BMW 323i Gear Box Specifications

	1st Gear	2nd Gear	3rd Gear	4th Gear	5th Gear
Standard ratio	3.83:1	2.20:1	1.40:1	1.00:1	0.81:1
Close ratio	3.76:1	2.33:1	1.61:1	1.23:1	1.00:1

V. WHY GEAR RATIOS USED IN AUTOMOBILE ARE NOT IN G.P

Ideal condition
To keep engine rpm in low fuel consumption region.
But,
In actual gears are not in G.P.?
There are several reason –

- G.P. based gear ratio would give the same change in engine speed for any shift but theoretically this is optimal use of engine speed range.
- Practically the vehicle power requirement changes so we can say vehicle speed is independent of gear ratio. The vehicle power requirement depend upon road resistance at a given speed.
- During up shifting of gear from 1st to 2nd gear the engine speed get half, in this situation engine get enough power to sustain vehicle speed and desired acceleration. But if we shift the gear from 4th gear to 5th it didn`t obtain enough power because at this gear it should give more speed.

In some manual transmission vehicles, there is an extra gear i.e. 6th gear (High Speed Gear). Its main function is to drop engine rpm at high speed to low fuel consumption region.

VI. ENGINE STALLING

The Engine requires to have a Particular rpm to run. When we try to engage the clutch from a full stop, Engine does not have enough Power to move the vehicle at that rpm and then *Engine Stalls* (it Stops).
If in 1st gear we engage clutch too quickly, engine tries to move the vehicle, forcing the rpm to drop down too low which causes Engine to stall.
If a car is at 100 kmph in 5th gear and then it slow down to 30 kmph in 5th itself. Then the Engine will likely to stall because the Engine wants to a particular rpm to run. But as the car is in 5th gear Engine rpm will go to lower than the minimum rpm at 30 kmph and Engine does not have enough power to accelerate at that *rpm* in that *Gear*.
During this period (Engine stalling), Engine will jerk badly until it stops/off (stall). This Jerking creates an extreme stress on engine components, which can leads to damage in engine (if it jerks for long time).
Let us take an example of Mahindra Scorpio (mHawk[120])
In 5th gear (3.401:1) at the speed of 30kmph the engine rpm are 853, which is very close to idle rpm and as we know at idle speed engine generates enough power to run reasonably smoothly and operates its accessories, but not enough to perform useful work such as moving an automobile.
If the vehicle is then switch in 3rdgear then the engine speed at 30kmph vehicle speed at1536 rpm. At this rpm the engine produce requires amount of torque to further accelerate the vehicle and also 3rd gear has a lower gear ratio which also increases its torque.

VII. VEHICLE SPEED ANALYSIS

Rolling radius & Rolling circumference
Rolling radius of wheel is required to calculate wheel rolling circumference.
Rolling Radius = 2 x pie x R
Where, R = Radius of Loaded tyre.
Now, when vehicle is loaded, its tyre makes a flat contact with ground and outer radius of tyre gets reduced.
Then,
R = 0.96 x r (approx.)
r = unloaded radius of tyre.
Rolling Circumference = 2 x pie x 0.96 x r

Calculate outer radius (r) of tyre
From tyre Specification: P235/65 R 17
Width of Tyre = 235 mm
Height of Tyre = 0.65 x 235 = 152.75 mm
Radius of Rim = 0.5 x 17 x 25.4 = 215.9 mm
Outer radius (r) = 152.75 + 215.9 = **368.65 mm**
Loaded radius of tyre = 0.96 x r = **353.904 mm**

Vehicle Speed
Speed of vehicle is Calculated by Engine rpm.
Speed (Kmph) = Rolling circumference (Km) x Engine rpm x 60 / (Gear ratio x Axle Reduction)

Let's Calculate Top speed of Mahindra Scorpio
Tyre Specification: P235/65 R 17
Rolling Radius of Tyre = 0.354 m
Top gear (5th Gear)ratio = 0.791
Axle reduction ratio = 4.3

Speed of vehicle at 4000 Engine rpm
Speed = 2 x pie x 0.354 x 10^{-3} x 4000 x 60/(0.791x4.3)
Speed = **156.87 Kmph**

Factors that affect's Speed of a Vehicle
1. Gear ratio.
2. Rolling Radius of Tyre.

Now first start with Gear ratio, For this take an example of Mahindra XUV 5oo & Mahindra Scorpio, Both of these are equipped with same engine series mHawk.

Table 9: XUV and Scorpio Specifications

	Mahindra XUV 5oo	**Mahindra Scorpio**
Top gear ratio:	0.87:1 (6^{th} Gear)	0.79:1 (5^{th} Gear)
Axle Reduction ratio:	3.115:1	4.3:1
Tyre Specification	P235/65 R 17	P235/65 R 17

Speed at 4000 Engine rpm,
Speed = *197 Kmph* Speed = *157 Kmph*

This is how the Top Speed of Vehicle vary with Gear ratio. Scorpio has 5 speed (with one overdrive) Gearbox while XUV has 6 speed (with two overdrive) Gearbox, XUV has one more speed gear which makes it faster than Scorpio. This is the reason that the Top speed of Scorpio is 160 Kmph and of XUV is 200 Kmph.
Now next is Rolling Radius of Tyre,
For this take Mahindra Thar, one is with standard tyres and other with customized tyres. Both have same gear box and Final Drive.

Table 10: Standard and Customized Mahindra THAR Specifications

	Standard THAR	**Customized THAR**
Tyre Specification	235/70 R 16	315/50 R14
Rolling radius	352.9 mm	321.6 mm
Top gear (5th) ratio	0.79:1	0.79:1
Axle Reduction ratio	4.3:1	4.3:1

Speed at 3500 Engine rpm

Speed = *137 Kmph* Speed = *126 Kmph*

This is how Speed will affect by changing different tyre. By using customized tyres speed of vehicle get decreases. Speedometer and Odometer readings will also get affected by using different tyres, they give reading by revs of tyre.

In case of customized tyres, as the revs remains same, Speedometer will read speed 137 Kmph but in actual it is 126Kmph. And Odometer will also read incorrect reading, it read 137 Km but in actual vehicle covers 126 Km. Hence, it also affects the fuel economy of the vehicle. It decreases with customized tyres.

VIII. HOW TO PARK AND WHY?

During Uphill

If a vehicle faces Uphill, always park in 1st (lower forward gear) Gear.

During Downhill

If a vehicle faces Downhill, always Park in Reverse (lower reverse Gear) Gear.

During uphill, Park in 1stgear and downhill Park in Reverse. It is Instructed to Park in lower gear, to use high Engine compression Force (1st & Reverse). It is the Compression force of engine which resist the motion of piston, and it resist Drive train to rotate and hence Wheels.

This is because when we park the vehicle in gear it produces stress on transmission system and if in case transmission system fails to hold the wheels, then vehicle will start rolling.

If a car is parked in 1st gear on downhill during this transmission fails and the car starts rolling, due this forward motion of car in 1st gear it crank the Engine and will start. This may lead to an accident. To avoid such type of accidents it is necessary to park the vehicle in Reverse (during downhill). Even if the car will roll, It rotates the Engine in opposite direction, hence it will not start.

IX. REFERENCES

[1] Graph 1, https://www.quora.com/what-is-the-relation-between-engine-RPM-and-engine-torque
[2] Technical Data, https://withyouhamesha.com/owner-manual.aspx
[3] Technical Data, https://service.tatamotors.com/content/owner-manual
[4] Milliken & Milliken , Race car vehicle dynamics, 1995
[5] Gillespie, Fundamental of Vehicle dynamics
[6] Close Transmission Ratio, https://www.wikipedia.com