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Computational modelling of six speed hybrid gear box and its simulation using Simulinkas an interactive tool of MATLAB

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Abstract
The paper introduces an idea which adds itself into contribution of getting best fuel economy of a passenger car when it is running at high speed on a highway. A six speed (forward) gear box is addressed in the paper which is controlled manually and automatically as well. The paper introduces an advancement in manual transmission gear box for passenger cars. Hydraulic circuit is designed with mechatronics point of view and resulting in making the shifting of gear automatically. A computational design is made of the Hybrid Gear Box (HGB) using CATIA P3 V5 as a designing software. A new gear meshing in 5 speed manual transmission gear box which synchronizes with the output shaft of the transmission automatically after getting command by the automated system designed. Parameters are considered on the basis of practical model and is been simulated by using Simdriveline as the Simulink tool of MATLAB r2010a. The mechanical properties of the components of the hybrid gear box is calculated on the basis of the functional parameters and with help of the fundamental and dependent properties formulation. The final result is the graphical analysis of the model forobtaining at least 15% fuel efficient than any of the vehicle of same configurations.
Keywords: -Gear box; Hydrodynamic; Simulink; Simdriveline; Synchronization; Simulations.

I. Introduction

In 2014, an automobile company "Honda" introduced 6 speed manual transmission vehicle named "Honda City VX (O) MT" Diesel variant with 1.5 Lit engine and 100 BHP power with 25.1 Kmpl fuel economy. Its ex showroom price in India is about Rs12 Lakhs. According to Indian Autos Blog (IAB) it was introduced in 2014 in India. According to NDTV venture Car and Bike (CAB), the selling of Honda city was 70000 units in the month of October 2014 and majority were of 5 speed manual transmission gear box and very few were 6 speed manual transmission in those 70000 units. Whereas cars with 5 speed manual transmission vehicles like Maruti Suzuki Alto with 250000 Units, Maruti Suzuki Swift Dezire with 200000 units were sold in the same month of 2014. These vehicles are also fuel efficient enough comparatively. Recognition of need of the idea introduced in paper came into consideration when costumers chose 5 gear manual transmission vehicle more than 6 speed manual gear transmission vehicle. Not only survey is been done of 2014, the same condition was noticed in 2015 also when vehicle like Hyundai i20, Honda jazz with 6 speed manual gear box being sold less comparative to 5 gear transmission vehicles. The recognition of promoting the 6 speed gear transmission technique in Indian market is brought into thinking, but its functioning is different from today's Indian 6 speed manual gear box technique. Hence, in the paper, 5 gear shifting will be as per the manual shifting by gear lever but the 6th gear will shift automatically after the 5th gear shift and after reaching certain speed. The combination of the gear ratios will tend the dynamics of vehicle to reach an optimum fuel efficiency. This technique can be applicable in any engine configured vehicle unlike the 6 speed manual transmission which is only applicable for the vehicle having engine of more than 89 Break Horse Power (BHP).

The concept of hybrid is been used and studied in the field by many researchers. Products like Battery Electric Vehicle (BEV), Mild Hybrid Vehicle (MHV) [1] - the research project of Land Rover. These projects of Jaguar Land Rover (JLR) claimed that their hybrid vehicle runs on battery as well as by engine in such a manner that battery power supports to increase the torque of the engine output and if the engine is not in use, the battery pull the vehicle at least for 30 miles [1]. Plug-in Hybrid Powertrain vehicle proposed a Compact Hybrid Planetary Transmission Drive (CHPTD) [2] which, uses battery power for actuation of breaks and clutch and driving the planetary gear arrangement. Parallel hybrid electric vehicle [3] uses hydrogen as the fuel and battery to run the fuel cell making the system hybrid and optimum in its functionality. Clutch less geared smart transmission (CGST) [4], a research article on gear shifting process is introduced which shows the gear shift without the clutch and ultimately using

battery and motor arrangement for the respective shifting. Hybrid Electric Vehicle (HEV) [6] which claims to be ecofriendly vehicle also have the same application of electric motor leading it to the word hybrid.

By referring these studies, the paper is superior in making the manual transmission automatic by shifting it to the top gear automatically as per the speed of the passenger car of about 1000 Kg is concerned. The study is focused at the moment in which the passenger car will run at a high speed and consuming the fuel as if the car is not thirsty. The paper introduces simple concept of driving the car through transmission gear ratios. After activation of the Hybrid System (HS) the dog clutch shifts the synchronization sleeve to the next gear ratio automatically by using the hydraulic circuit as the system of automation.A hydraulic circuit is designed which includes double acting cylinder followed by solenoid actuated direction control valve for directing the shifting mechanism from manual to automatic according to mechatronics point ofview.

The gear ratio of the new added gear is less than that of the over drive gear ratio of the gear box which tends to move the vehicle at high speed and at constant engine speed resulting in lower fuel consumption rate. The model shows the simplicity in the idea of getting the 6^{th} gear ratio for the transmission to the output shaft which will tend the driver to press the acceleration paddle in small amount and hence getting an optimum fuel economy on high speed.

The aim of the researched design is to make the 5 speed manual transmission into 6 speed and more efficient and user friendly. More than 52% of the world population is still using a manual gear transmssion vehicle. If a vehicle contains more than 5 speed forward gears transmission system, then also the design can be accommodated into the system and ultimatly it will be efficient in the case.

II. Model and theory

A basic layout of the model assembly is shown below,

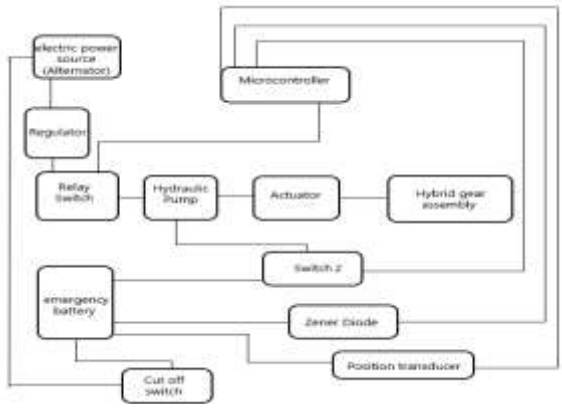

Fig .1. Model assembly Layout

In fig (1), Electric power source is the Alternator of the car which have two main outputs for the model. One of the connection goes to relay switch and another to the emergency battery. The relay switch is Electrostatically actuated 4T relay switch [7] which is used for the supply of current according to the need of the system. It is also flexible in switching voltage with energy efficiency of greater extent [7]. The car alternator is the Lunden Alternator [8] which can give a good amount of electric energy to the componentseven at 600 RPM of the engine speed. Between switch relay and the emergency battery , regulator and the cut-off swtich is been added for the current to flow according to design need. A 12 volt battery is been added for the safety point of view. A hydraulic pump followed by the relay swtich is being situated at base rail of the vehile. A double acting cylinder as the output of the hydraulic circuit is further actuating the hybrid system of the model.

The 12 volt emergency battery is further connected by the microcontroller followed by the connection with position transducer, zener diode, and the switch which lays the connetion to the hydraulic pump. The position transducer is used as Liner Variable Differential Transformer (LVDT) [9] which can detect the position displacement of the rod of actuator of the hydraulic circuit. Atmega 16 microcontroller is used for the model [10]. Zener diode is used to send limited amount of current to the microcontroller and for other safety purpose for the Integrated circuit (IC) of the mechatronic arrangement. A computaional code is saved in the microcontroller for performing functions like to switch on the relay switch, to read the speed of the vehicle and work accordingly.

The hybrid system get actived when the vehicle crosses a certain speed and this speed is sensed by the Vehicle Speed Sensor (VSS)[11] which is already present in the vehicle itself and sends the signal to the respective microcontroller (MC) for further process.

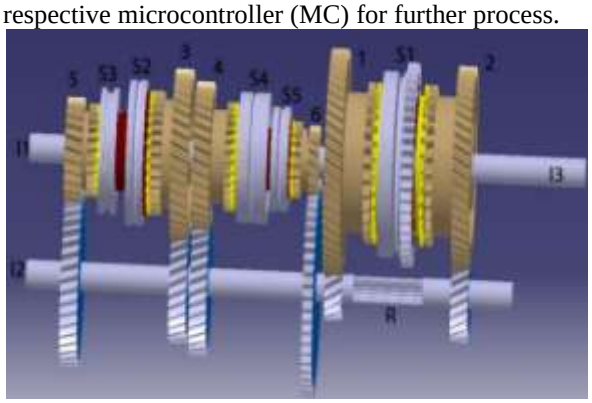

Fig.2. Six speed (Forward) hybrid gear box

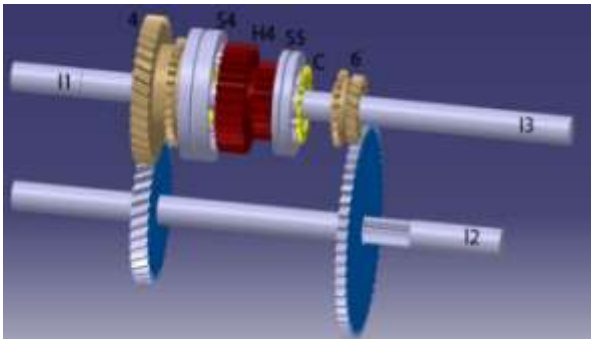

Fig .3. Dissambeled figure of the proposed model

A computational design of the desired gear box is shown in Fig (2). When the hybrid system comes into action then the gear 5 and gear 6 comes into use with the help of the double acting cylinder which is shown in Fig (5)

Fig (2) and Fig (3) shows the assembled and dissembled arrangement respectively for the activation of the hybrid gear system and also model of the proposed gear box. Gear ratio 6 is the gear meshing added to the 5 speed manual transmission. The gear hub H4 has two sections. One is for the 6th gear sleeve S5 and the other is for the sleeve S4 for the 4th gear activation. The rack gear (refer Fig (4)) with the shift shaft is connected with the sleeve S5 and S3. C is the brass material synchronization ring which protects the sleeve, hub and gear from relative slipping. Shaft I3 as the output shaft obtains the 6th velocity gear ratio after the sleeve S5 synchronizes the speed of gear 6 to the hub H4.

The proposed gear box can be modified according to the vehicle need but the concept of adding the extra gear meshing and actuating it automatically will be the same for all the vehicles. The gear ratios can be changed according to the vehicle mobility.

The housing of the gearbox can be done in Gatreg MT series gearbox housing [12]. The material of the gear and other components are of case hardened Steel of grade C61 [13].

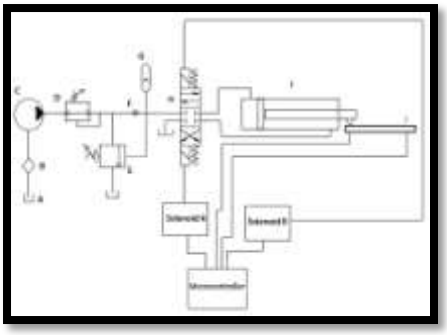
Fig.4. the Hydraulic circuit

Fig (4) shows the hydraulic circuit consists of a solenoid actuated direction controlled valve which is been referred from [14]. The double acting cylinder I is assembled with the position transducer LVDT [9], and then the signal is sent to the microcontroller [10] for the specified purpose. The solenoid is used for positioning the rod of the double acting cylinder J which gets signals from microcontroller. Solenoid A is for reverse stroke and solenoid B for the forward stroke of the rod of double acting cylinder.

This hydraulic pump is mounted besides the bell housing [12] of the gear box and that hydraulic pump is getting the power from the alternator [8] of the car. The relay [7] is acting as a switch which is activated whenever the speed of the car reaches the favorable speed for the system. Hydraulic pump is used to actuate the double acting cylinder and it further actuates the gear rack and gear pulley for the synchronization of sleeve to engage the 6th gear and disengage the 5th and vice versa. Refer Fig. 5

When a car driver takes the car to a speed of 70kms/hour (Experimental speed),at this time the fifth gear is already in use and the 6thgear gets engaged by synchronizing through sleeve which is mounted on the output shaft gear hub with a simultaneous action of disengagement of the fifth gear thus switching on the hybrid system. When the person abates the speed of the car and brings it down to 60 km/hour the system simultaneously disengages the hybrid gear system hooking the fifth gear back and not engaging it again before completion of 1 minute of its disengagement hence, preventing the wear of the system. This operation is calculated by a microcontroller checking the switching on and off of the pump and hence an even amount of turning on of pump results in the disengagement of the system.

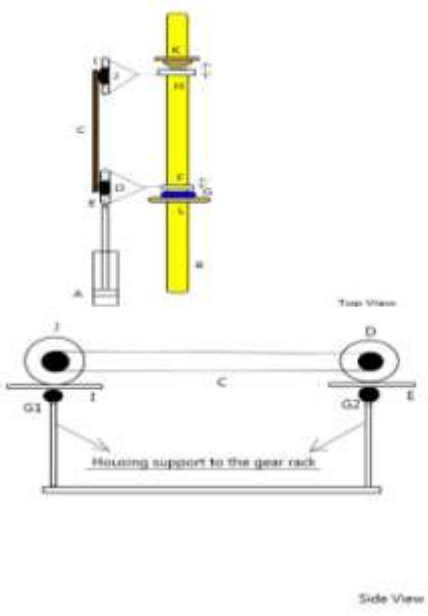

Fig.5. Gear shifting mechanism with Top view and Side view

In this paper, there are three shift shafts which transmits the motion to engage the first 4 gears into

use. The 5th position of the gear liver switches the circuit of the hybrid system. After this, the microcontroller starts reading the speed of the car and acts accordingly to make the hybrid system work efficiently. In neutral condition the sleeve for the 5th gear and 6th gear is in disengaged situation. When the gear liver is in 5th gear position, the double acting cylinder makes a reverse stroke and hence the sleeve of 5th gear activates the 5th gear transmission speed. After 70 KM/hour, the double acting cylinder takes the forward stroke for the rotation of the gear pulley and the 6th gear synchronization takes place. If the driver suddenly changes the gear from 5th position to the 3rd or any other lower than 5th for controlling speed, the activation action of gear lever on the 5th position is be disengaged andget switched off and the gear 5th and the 6th gear comes to the neutral position again and the car runs on the respective gear transmission. In this phenomenon, the main role is of position transducer and the microcontroller of the system. The microcontroller is in full knowledge that at what position of the piston rod, which gear is essential to actuate.G1 and G2 (From Fig (5)) are on the plane parallel and on offset from the plane of supporting pillars.

At the time of shifting the pressing of the clutch lever is being pressed accordingly during the shifting of gear in manual way and in the automated way as well. The fork lever of clutch is present near the bell housing of the gear box.

III. Results and discussions

a. *Functional parameters and formulation*

Table .1. Gear specification

Gear	Velocity gear ratio
First gear	3.8
Hybrid gear	0.299
Second gear	2.08
Third gear	1.4
Forth gear	1
Fifth gear	0.8
Differential gear ratio	3.6
Tire Radius	56 cm

Table .2. Hydraulic Pump Specification

Properties	Values
Pump	Liquid handling piston pump
Reservoir required	6inch^3
Power required	1/3 horsepower
Required pressure	35 psi (For hybrid System)
Oil type	Biological degradable oil (Polyglycol with viscosity index more than 200) and the density is 1007.9 gram/m^3

$$F = \frac{1}{H_d}\left(\frac{fNV_d}{2000\,E} + \frac{P}{E}\right)$$

The above formulation was done by [21] for fuel consumption rate relations with physical components.

Table.3. Engine and Fuel Specification

Properties	Notation	Parameters
Engine type	-	4 Cylinders inline
Fuel type	-	Diesel
Energy density of fuel	H_d	32.19 MJ/Lit
Friction mean effective pressure	f	0.98 bar
Engine efficiency (assumed)	E	50%
Engine displacement	V_d	1400cc
Engine Speed (RPM)	N	-
Tractive power	P	Zero (Assumed)
Stroke/ Bore Ratio [15]	-	1.3

b. Simulated ray diagram for obtaining results.

Diesel engine block with its throttle signal (Signal builder) is placed with its all specifications. The connections are made by drag and drop technique in simulink MATLAB. After the connections of the inertias and the driveline environment [16] , the hybrid gear box connections starts and the labeling of the friction clutches and simple gear blocks are made according to the schedule shifting of gears. All the connections have a single output..

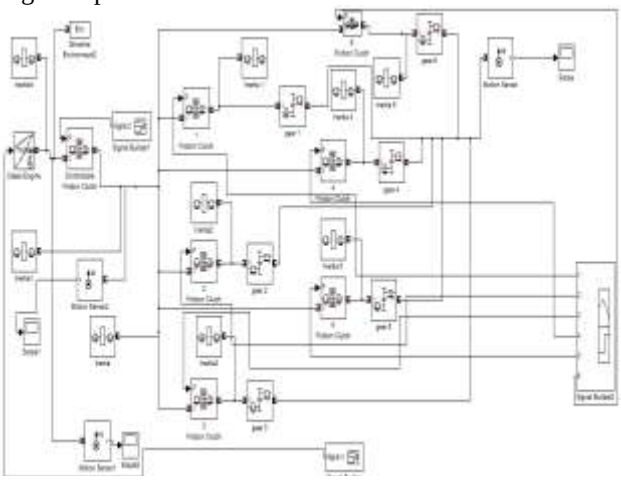

Fig.6.Simulated ray diagram using simscape from simulink library of MATLAB r2010a

Signal builder (Ref Fig. (6)) plays an important role in the simulation of the model as it decides to

send the signal of actuation which is totally dependent upon time [16]. The maximum time range for the simulation is kept to be 0-50 sec. The Zero crossing algorithm [16] is enabled during the simulation so as to decrease the time for simulation. Controllable friction clutch [19] have 6 friction layer and the maximum angular velocity tolerance is decided by the driveline environment block [16] shown in the figure (6).

Clutch schedule for all the six gear is built in signal builder consisting of 6 output ports and the signals are pulse type signal which is totally dependent upon time and engine speed.

Each simple gear bock is provided with a controllable friction clutch block which is controlled by the signal builder and its scheduling is made so that each gear block gets activated in a systematic manner so as to make a time dependent impact on the output shaft's motion sensor block of the Simulink block diagram. Inertia blocks are connected to each friction clutch block and gear block arrangement so as to get the exact shaft condition which connects the respective gear block, clutch block, and the output shaft.

The MATLAB function ode45 is used for the simulation [17] which solves the non-linear ordinary differential functions formulated on the dynamics of the gear shifting mechanism followed by the clutch schedule. Every simple gear block is provided with a controllable friction clutch and they are free when the system is in neutral condition unlike the main friction clutch which is locked always when engine is on.

b. Graphical result of the simulated ray diagram.

Fig.7. Engine speed Vs. Time graph

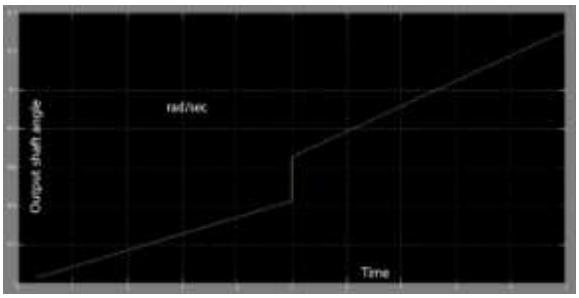

Fig.8. Output shaft angle Vs. Time graph leading angular velocity

In Fig (8), a rapid elevation in the velocity graph is seen due to shifting of the gear from 1st to 2nd. Due to difference in the velocity gear ratios and difference in linearity in angle of deflection of 0.01 rad is seen at a constant time. This deflection is the magnified image of the change in angle during the gear shift. After the shifting of gear, the graph is proportionally increasing with time.

On the other hand in Fig (7), the engine speed is varied with time and is non-linearly proportional with time. The nonlinearity is due to the changes in moment of inertia of the shafts driving the system. Shafts like Main Transmission Input Shaft (MTIS), the counter shaft, and Main Transmission Output Shaft (MTOS) have different moment of inertias according to their mass and radius.

After certain speed, the engine RPM is increasing with the slope of the graph tending to zero and on the other hand the speed of the output shaft is increasing. That is at the time when slope of the engine speed graph decreases the vehicle is shifting towards over drive speed ratio and as the gear get automatically shifted to the 6th gear ratio, the speed still increase but with a constant RPM of engine hence, reducing in the fuel consumption even at high speed of car driven on highway. The Practical model referred for the paper is giving 22 KM/Lit of mileage and after calculating the model formulation and simulation, same car is giving at least 26 KM/Lit when running at high speed on highway.

IV. Conclusions

a. The simulated ray diagram for the proposed model by using Simdriveline as the Simulink tool of MATLAB r2010a [20] and the graphical result of engine RPM Vs. time and of angular velocity by using motion sensor block of the Simulink library are successfully obtained . [16]

b. The aim of getting the optimum fuel efficiency and resulting it in increase of at least 15% is successfully obtained by the graphical analysis.

c. In case if the loading crossed the bearable strength of the components, a provision to overcome the problem is bearing [18] is used between the 6th gear and the output shaft.

d. Command line for the working of the microcontroller is been formed and saved into the memory device of the microcontroller unit with help of the specialized engineer.

e. Gear pulley - chain transmission and the shift-shaft mechanism has been developed for the respected hybrid gear system.

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Nomenclature

. (For Fig.2)
1 – 1st gear ratio
2 – 2nd gear ratio
3 – 3rd gear ratio
4– 4th gear ratio
5 – 5th gear ratio
6– 6th gear ratio
I1 – Main transmission input shaft
I2 – Counter shaft of the transmission
I3 - Main Transmission Output shaft
R - Reverse gear teeth on the countershaft
S1 – Synchronization sleeve for actuation of 1st and 2nd gear
S2 - – Synchronization sleeve for actuation of 3rd gear
S3 - – Synchronization sleeve for actuation of 5th gear
S4 - – Synchronization sleeve for actuation of 4th gear
S5 - – Synchronization sleeve for actuation of 6th gear

.(For Fig.3)
H4 – Gear Hub carrying synchronization sleeve.
C – Synchronization ring

. (For Fig.4)
A – Hydraulic oil reservoir
B, D – Filter and Pressure regulator respectively
C – Hydraulic Pump
E – Pressure Relief Valve
F – Check valve
G – Accumulator
H – 4/2 DCV Solenoid Actuated
I – Double acting cylinder
J – Position transducer (LVDT)

. (For Fig.5)
A – Double Acting Cylinder
B- Output shaft
C – Chain drive/ Belt drive [5]
D – Gear Pulley for 6th gear
E – Gear Rack for 6th gear
F – Synchronization Sleeve for 6th gear
G – 6th gear
H – Synchronization sleeve for 5thgear
I – Gear rack for 5th gear
J - Gear Pulley for 5th gear.
K – 5th gear
L – 1st gear
G1, G2 – Roller to support rack to move over pillar

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