

AN AUTOMATED SHIFTING MECHANISM FOR A SEQUENTIAL TRANSMISSION SYSTEM IN AN ELECTRIC VEHICLE

Utkarsh Ravi

ARAI Academy

The Automotive Research
Association of India – 411038,
India

raviutkarsh@gmail.com

Pratik S. Singh

School of Mechanical

Engineering,

VIT University, Vellore –
632014, India

pratik.ssingh22@yahoo.c
om

Anudeep Mathur

ARAI Academy

The Automotive Research
Association of India – 411038,
India

anudeepm94@gmail.com

ABSTRACT

The world is moving towards a cleaner and sustainable technology; an electric car is one of them. Nowadays most of the electric cars are using manual transmission which can be converted in to semi-automatic and automatic transmission by installing an electro-pneumatic shifting mechanism. In this article, work concerning product design of the shifter on a sequential transmission is described. The mechanism is achieved by using a pneumatic cylinder, sensors, solenoid valves, air reservoir, microcontroller and paddle shifter. The gears can be shifted either by the driver or an electronic control unit (ECU). ECU takes input from the paddles attached behind the steering wheel or vehicle speed sensor and the gear is shifted by the pneumatic cylinders, controlled by a microcontroller via solenoid valve. Simulations of the vehicle shows an increment of 26% in the top speed and 28% in the average power along with improved cornering velocity with respect to the vehicle without shifter. The automated shifting mechanism is much more helpful for straight line path as it changes the gears to achieve maximum acceleration in minimal time. This Electro-Pneumatic shifter setup is cost effective and gives an excellent opportunity to have a feel of driving a sports vehicle.

General Terms

ECU - Electronic Control Unit is an embedded system that controls one or more of the electrical system or subsystems.

Pneumatic- Pneumatics makes use of gas or pressurized air.

Solenoid- Solenoid is a long straight coil of wire, can be used to generate a nearly uniform magnetic field.

Sprocket - A sprocket wheel is a profiled wheel with teeth, cogs, or even sprockets that mesh with a chain, track or other perforated or indented material.

Keywords

AMT; automated manual transmission; electric vehicle; electro pneumatic shifter; pneumatic shifter.

1. INTRODUCTION

From centuries we have been talking whether technology is a boon or bane and yet have not arrived at any conclusion, instead we are developing new technologies every day which is much cleaner and greener in form. C.N. Spentzas (1993) has discussed the reduction of air pollution and greenhouse gasses effect in urban areas by replacing gasoline powered cars by electric cars [1, 13]. Israr Ahmed and

KumKumDewan (2007), states just by opting Electric Vehicle (EV), the pollution can be reduced to 75,991 tons from 1,01,051 tons per year [2]. Chetan Maini once said, "Though electric vehicle technology is at a nascent stage in India, but definitely REVA Electric Car Company sees a long and bright future for electric vehicles in India" [16].

An electric motor over the conventional internal combustion engine provides high torque output over a wide range of rpm. It provides very high torque at low speed which is good for fast acceleration and obstacle negotiations (M. Ehsani et al., 2003) [3, 13]. The design of the transmission system of an Electric vehicle plays a significant role in determining the vehicle dynamic performance (Minghui Hu et al., 2014) [4], making installation of gearbox a favorable concept. Paul D. Walker et al. (2015) observed in an electric car that two speed transmission provides more consistent average cycle loss and improved low speed acceleration [5]. Since transmission losses are more in automatic transmissions, development of an automated manual transmission is convenient and cheaper [8, 9, 11]. The automated manual shifting implementing pneumatic cylinders, smooth shift quality and high driving comfort was observed (Han-Sang Jo et al., 2000) [6]. Also thinking and processing an information by mind takes time while a vehicle has ability to reach 100 *Kmph* within seconds hence shift time plays a crucial role in acceleration (Ping C. 2004) [9].

The design proposed here is developed keeping the passenger vehicles in mind, hence it, will increase the driver comfort also the net time consumption of the process will be quite less than required in manual shifting [11, 12].

2. DESIGN OF POWERTRAIN

Z. Rahman et al. (2000) States that some of the important parameters to be considered for motor selection is Torque density, Inverter size, Extended speed range-ability, Energy efficiency, Safety and reliability, Thermal cooling, and Cost [10]. Two Agni Motor 95R Series motors are used in series, operating at 71 *rpm/volt* at 72V [3, 7]. The Power supply to these motors is by 164V Lithium Polymer battery. The Motors are coupled together using a flexible coupling in between to get a net output or required 108 *Nm* torque. This coupling can withstand torsion of 60*Nm* (max torque of one motor).

The power from motors is transmitted to the differential via sprocket chain drive in a two-step reduction. To achieve the required ratio, the gearbox is coupled after one fixed reduction

and there is a final drive reduction on differential sprocket. [15].

Two proximity sensor are used i.e. at the gearbox output sprocket and the final drive sprocket. These sensors constantly monitor the rpm of the sprocket and sends a signal to the ECU which further processes it.

3. DESIGN OF ELECTRONIC SYSTEM

The complete shifting mechanism is controlled using low voltage circuit. There are three limit switches each for up shift, down shift and auto/manual selector. Upshift and downshift limit switches are installed in a paddle shifter. The paddles are placed behind steering wheel for its ease in accessibility. The auto/manual switch is placed on the dashboard. When the driver actuates any of the switch, voltage rises in the circuit from 0 to 5V.

The ECU is an Arduino UNO based microcontroller. It has an Atmel ATmega328P microprocessor. It is an 8-bit microprocessor having 32 KB flash memory. Arduino Uno board has 14 Digital input/output pins, 6 Analog input/output pins. The microprocessor takes seven input values in total from the input pins. Five digital input values are obtained from five different Limit switches. The other two analog inputs come from the proximity sensor.

A Proximity sensor works on the principle of detecting any metal present in the proximity of the sensor. The change in signal while passing a hole on the sprocket is counted by the microcontroller and velocity is calculated.

4. DESIGN OF PNEUMATIC SYSTEM

Figure. 1 represents a schematic diagram of a Pneumatic system. The system operates under the application of gaseous fluid which in our case is Nitrogen. The nitrogen is stored in a pressurized container called Reservoir and is regulated to a working pressure by a Pressure regulator, specified for 50 bar. The output pressure can be varied using a regulator and set to 6 bar in our case.

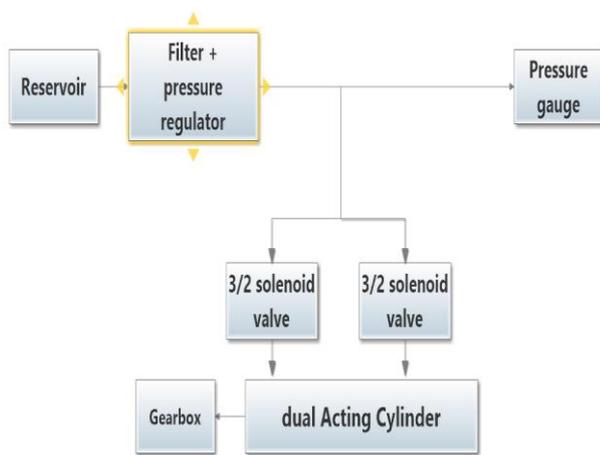


Figure. 1 Schematic diagram of Pneumatic system

The Solenoid is an intermediary which controls the amount of flow of pneumatic fluid from the reservoir to the Cylinder. Two 3/2 solenoid valves having three ports and two position is used for upshift and downshift separately. These valves are connected to pressure regulator via pneumatic lines which are designed to withstand thermal and mechanical stress occurring due to flowing N2.

The Selector fork is a Y shaped fork lever designed to transfer force from the pneumatic piston to the shifting pedal. The Y shaped part of the fork is bolted with the shifting pedal while the other end fastened to the piston. As the piston is pushed by the air, the shifting pedal is turned about the bolting point like a ratchet mechanism.

On pressing the paddles, signal from the driver will reach to the ECU in the form of an electronic input. The board will read the input and accordingly send an actuation signal to one of the two solenoids.

Position sensors installed on the pneumatic cylinder checks the initial position of the piston inside the cylinder. As the piston reaches at the edge of cylinder, sensors give input to the ECU board and it ceases the flow of N2 gas from the solenoid valve.

5. SELECTION OF GEAR BOX AND SHIFTING OF GEARS

Simulations are done over a length of 75 m straight track to achieve maximum acceleration and velocity in minimal time as per the considerations shown in Table 1. Iterations were done and a three stage gearbox with gear ratios 2.77, 1.88, 1.38 respectively is selected to improve the performance of the car. Figure. 2 represents the distance covered and time taken with respect to the speed of first gear. Observing the graph 49 Km/h was selected as the top speed as the time taken is less with rest to the distance covered.

To obtain better efficiency from the vehicle, gears must be shifted at correct stage [8]. When a gear is shifted by a pneumatic cylinder it takes an average time of 0.6 seconds. During the shift period the power supply from the motor is stopped for proper engagement of the gear and smooth shifting similar to the application of a clutching mechanism.

In this 0.6 seconds the vehicle starts to decelerate, to reduce cumbersome in the calculations constant velocity of vehicle is assumed. Figure. 3 represents the distance covered and time taken during the first shift.

Table 1. Characteristics of the Vehicle

Mass of Vehicle (with Driver)	375 Kg
Wheel Diameter	0.54 m
Maximum torque of Motor	54 Nm
Drag coefficient	0.85
Density of Air @ 25°C	1.183 Kg/m ³
Target Distance	75 m

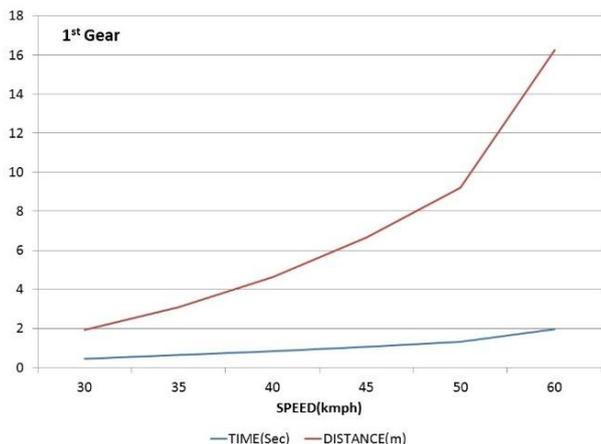


Figure. 2. Distance (m) and Time taken (s) vs Speed (Kmph) during 1st shift of gear.

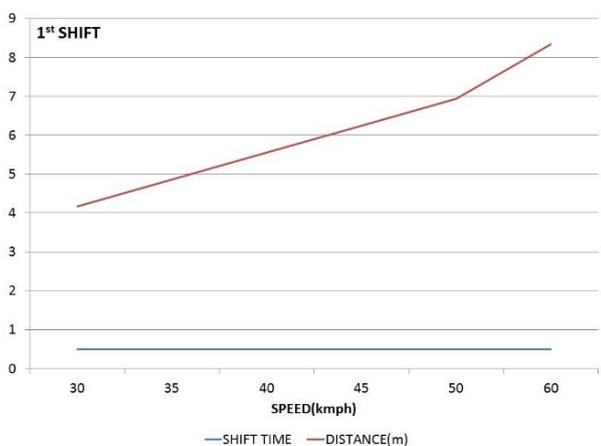


Figure. 3. Distance (m) and Time taken (s) vs max Speed (Kmph)

Figure. 4 shows distance covered, distance remaining out of 75 m and corresponding time taken vs max speed obtained in the second gear. Again we can observe at 72.2Kmph the distance. covered and time taken is optimum. While Figure. 5 represents distance covered during gear shift.

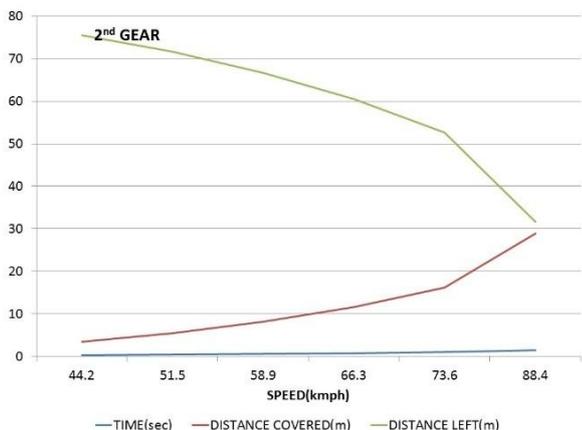


Figure. 4. Distance (m) and Time taken (s) vs Speed (Kmph)

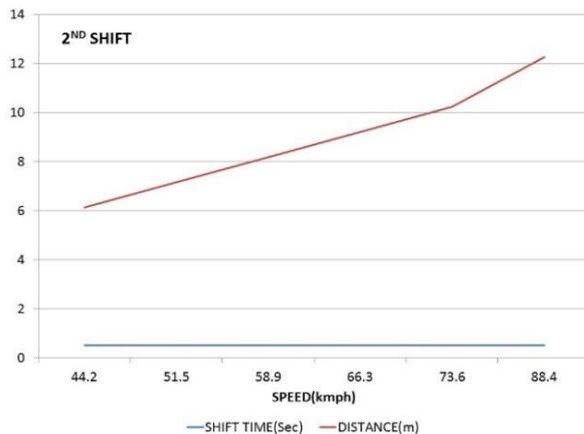


Figure. 5. Distance (m) and Time taken (s) vs Speed (Kmph) during 2nd shift

The third and final gear must be designed in such a way that the remaining distance out of 75 m must be covered with maximum velocity and shortest time. In Figure. 6 green line represents the distance remaining and the red line is the distance covered, the point where these two lines intersect is the point where distance covered is equal to distance remaining. Hence the speed i.e. 92 Kmph at intersection point is a very favorable speed. But due to design constraints and availability of gear box the selected gears and gear ratio the max speed of third gear comes out be 98.35 Kmph.

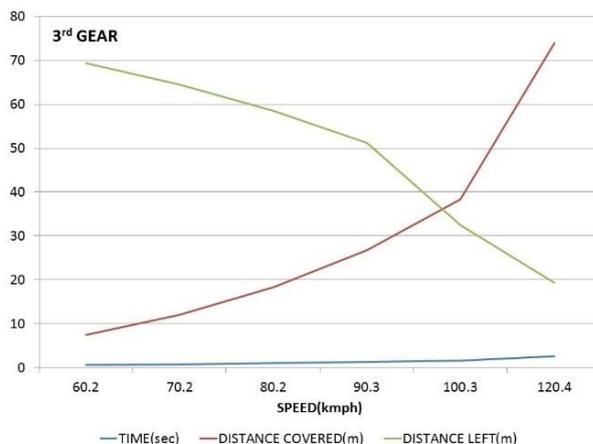


Figure. 6. Distance (m) and Time taken (s) vs Speed (Kmph) when engaged in 3rd gear

6. DESIGN ALGORITHM

The ECU programming begins with initializing the corresponding digital and analog input and output pin with pin numbers. The program then checks for certain parameters as a safety measure. Inputs from the two proximity sensor is compared and checked for a 5 % error while reservoir pressure must be above minimum level. After satisfying all the criteria driver is notified. Till this program runs once every time the vehicle is switched on.

The driver has a provision to choose between automatic and manual shifting. Figure. 8 represents the algorithm for manual shifting. The program starts with the count as one (current engaged gear) and verifies the pressure of reservoir. When microprocessor observes a High input from the

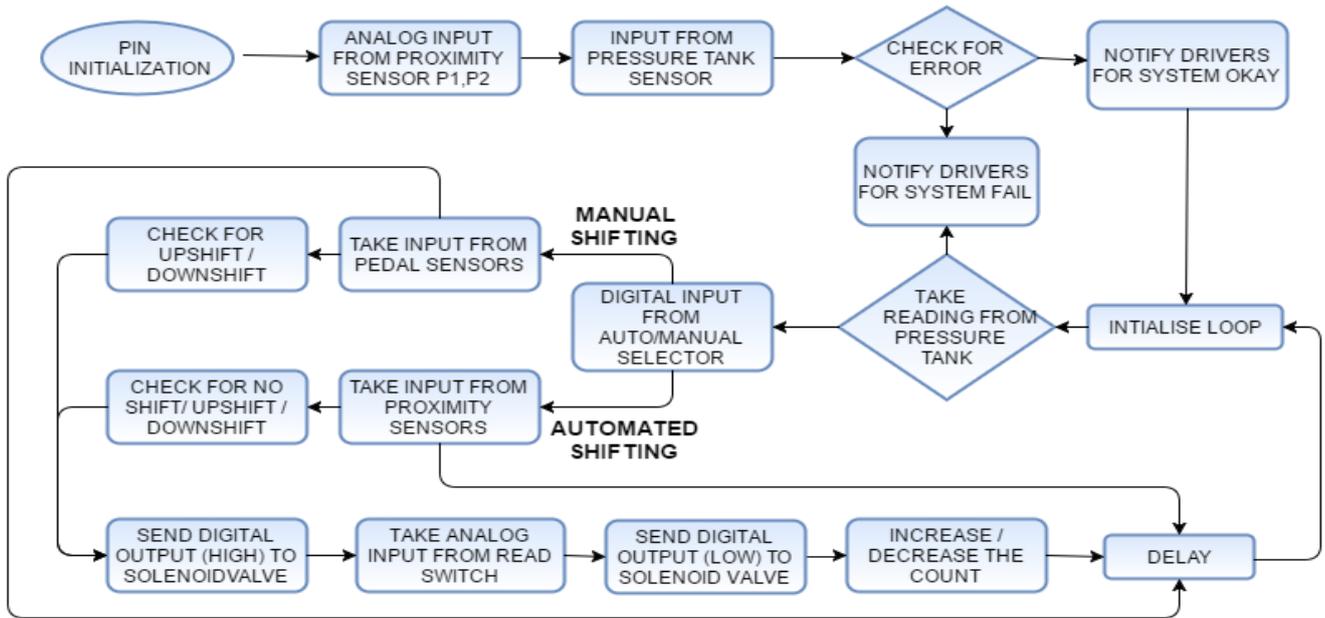


Figure. 7. Algorithm of Automated and Manual Shifting

upshift/downshift limit switch, corresponding solenoid is activated else it skips to the last step. After the actuation of the solenoid, the piston moves downwards and hits the position sensor, hence the ECU sends a Low output to the solenoid. Similarly, downshift is performed. The Count is increased for an upshift and is decreased for a downshift. Once the shifting process is complete program is delayed for 10 ms to get manageable data else the system will overflow with the incoming data.

Figure. 7 represents the algorithm of automatic shifting. The program again starts with the count as one and reservoir pressure check additionally checking vehicle speed via two proximity sensors. Once the proximity sensor reads the velocity of 49 Km/h or 72 Km/h the ECU initiates the above explained upshift mechanism.

When the ECU monitors 40 Km/h or 68 Km/h, it initiates a downshift. This difference in upshift and downshift is kept to reduce the rapid shifting of gears while cruising on the race track. The loop again ends with a 10 ms delay.

7. PERFORMANCE ANALYSIS

A performance test was carried out using Optimum Lap software. For analysis various parameters such as rolling friction, lateral acceleration, radius of the tire, density of the air, drag coefficient etc. were considered as per the specifications and real time scenario

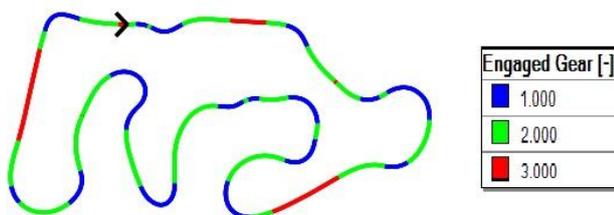


Figure. 8. Engaged gear track map

To analyze the effectiveness of the pneumatic system, the vehicle is simulated twice under similar parameters, once with compound sprocket chain system and once with pneumatic

shifter. Figure. 8 resembles to Formula Student Germany endurance track. The different colors on the track represents the engaged gear as shown in the column. The significance of installing a gearbox can be observed at the corners as time to overcome the corners reduces in comparison to the vehicle with no gearbox. Figure. 9 and Figure. 10 represents the distribution of the speed of the vehicle installed with gearbox and without gearbox respectively over the endurance track. While designing a powertrain for any vehicle (with or without gearbox) the requirements of both the acceleration and endurance must be taken into account. The vehicles must be able to cover the distance of 75 m within 5 seconds of time.

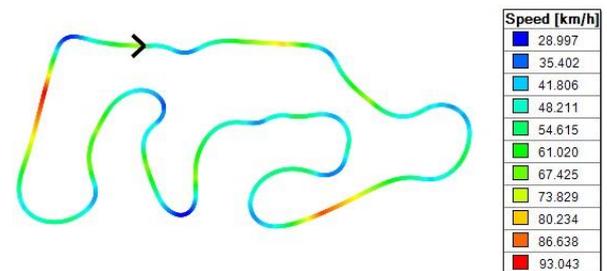


Figure 9. Speed track distribution with gearbox

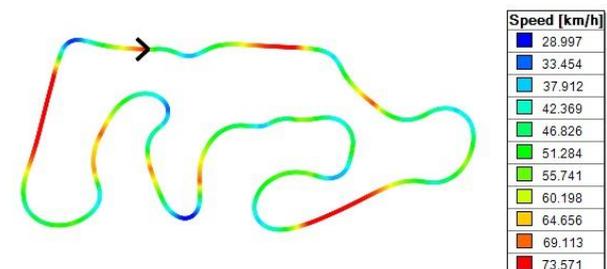


Figure. 10. Speed track distribution without gearbox

On comparison of both the figures it is observed that the average speed and the speed at corner of the vehicle with pneumatic shifter is greater than vehicle without gearbox. For the straight portion of the track, top speed increases by approximately 20 Km/h in case of gearbox. Also vehicle is

able to maintain higher speed for long duration with gearbox, hence reduced time.

Figure. 11. represents a graph between the engaged gear and elapsed distance (m). According to the number of shifts and laps net volume of N2 is calculated and filled accordingly into

gearbox is able to run at maximum power for longer duration of time. While comparing elapsed distance (m) and motor torque (Nm) in Figure. 14 and Figure. 15 under similar conditions, the vehicle with gearbox achieved maximum motor torque for greater duration than the vehicle without gearbox embarking maximum acceleration for longer

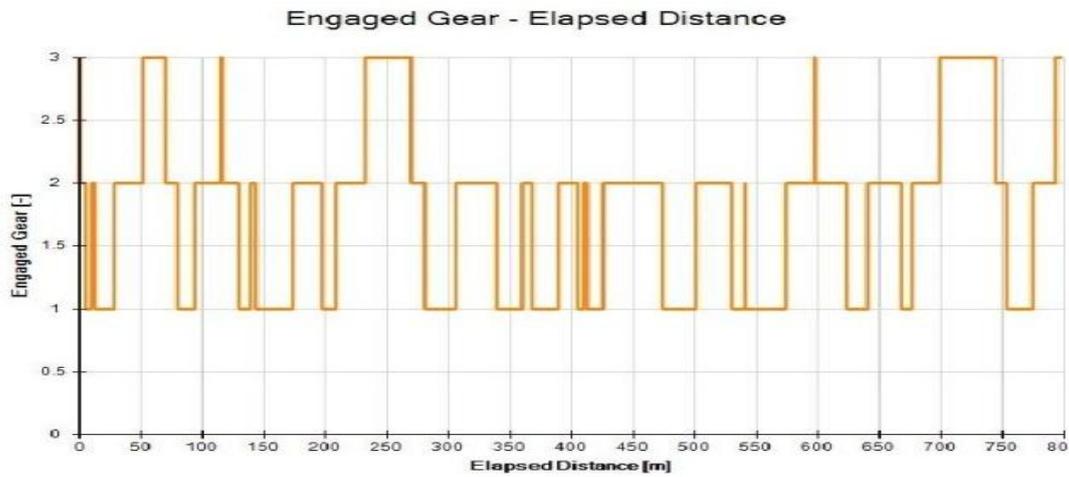


Figure 11. Engaged Gear vs. Elapsed Distance (m)



Figure 12. Motor Power (W) Vs Elapsed distance (m) without gearbox

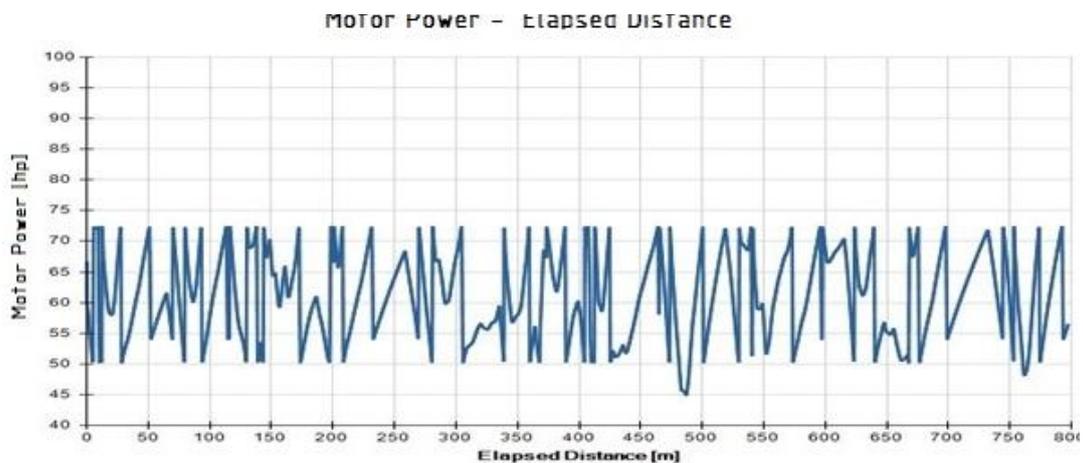


Figure 13. Motor Power (W) Vs Elapsed Distance (m) with gearbox

the reservoir.

On comparing elapsed distance Vs motor power in Fig. 12 and Figure. 13 it is inferred that the motor of the vehicle with

duration. This helps to attain slow in and fast out corner, reducing the total time to cover one lap.

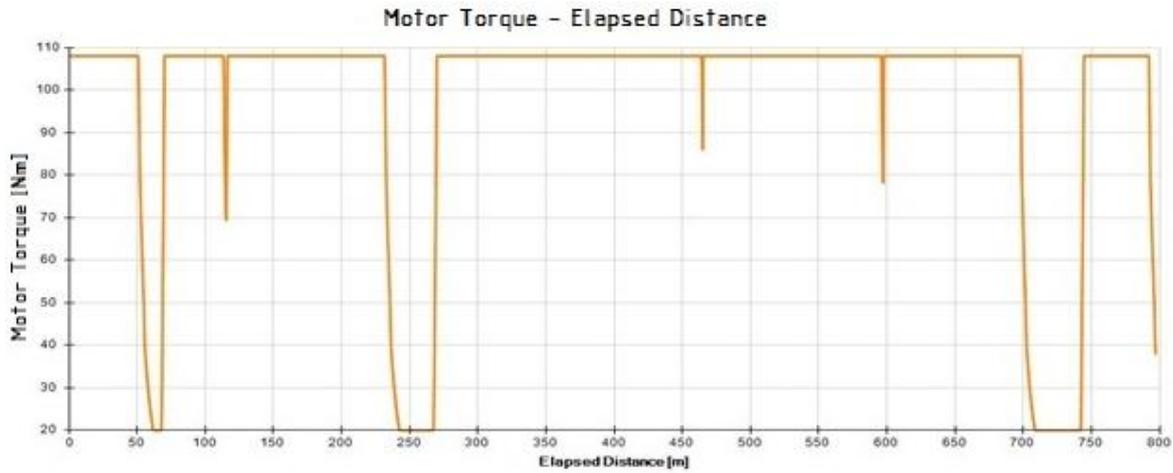


Figure 15. Motor Torque (Nm) Vs Elapsed Distance (m)

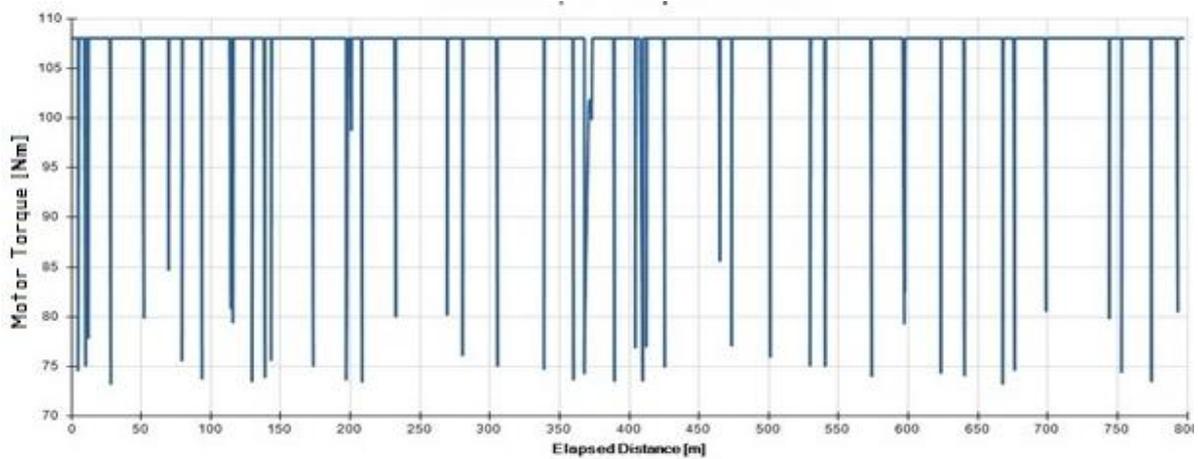


Figure 16. Motor Torque (Nm) Vs Elapsed distance (m) with gearbox

Since automatic gear shifting requires a range of speed fixed for each gear theoretical range of speed can be optimized using real time scenario simulation to obtain better performance. In Figure. 8. & Figure. 10, speed variation in some portion of the lap is minimal. The value of maximum or minimum speed for any gear ratio must not fall under this variation to avoid several unwanted shifting of gear.

8. CONCLUSION

An electric vehicle is one the major development in itself, while developing an Electro-Pneumatic shifter to obtain a consistent output is another achievement. As stated an electric car doesn't necessarily need a gearbox. But its implementation can vary the output a lot.

Motor selection, design of the transmission and the gear shifting mechanism plays a vital role in the vehicle performance. Electro-Pneumatic shifting mechanism reduces the shift time to only 50 ms, much faster than any manual shifting. The driver enjoys the feel of both paddle shifting and automatic shifting in a single setup. With an optimization in the transmission design, a maximum acceleration of 8.9 m/s² and a top speed of 98 Km/h was achieved, which is a 31.5% increment with respect to the vehicle without gearbox. Simulation over an 800 m curved track in Optimum Lap software shows an increment in maximum speed & average power output of 26 % & 28 %, respectively. By observing the graphs above it can be inferred that the vehicle with gearbox

runs within its most efficient region for a longer duration allowing maximum possible torque, acceleration and power. Other simulation also shows an improved cornering stability along with a better in and out cornering speed.

The product is easy to install on any vehicle and is cheap when compared to the current automatic transmission vehicle available in the market. The design can be modified to be installed in a gasoline powered vehicle with an addition of pneumatic cylinder for clutch actuation.

9. ACKNOWLEDGEMENT

This research was highly supported by Team Ojas. We thank all our peers from Team Ojas, who provided insights expertise as well all the accessories for successful completion of our research, although they may not agree with the interpretation/conclusion of the paper.

We would like to show our gratitude to the faculties of VIT University and The Automotive Research Association of India for sharing their pearls of wisdom in the time of need.

At last we thank our friends and family for motivating us continuously towards our goal.

10. REFERENCES

[1] C.N. Spentzas, 'Towards an electric vehicle policy', Int. J. of Vehicle Design 1993 - Vol. 14, No.2/3 pp. 118 - 123,1993

- [2] Israr Ahmad, KumKumDewan, 'Electric vehicle: a futuristic approach to reduce pollution (A case study of Delhi)', *World Review of Intermodal Transportation Research* 2007 - Vol. 1, No.3 pp. 300 – 312,2007
- [3] Ehsani, M.; YiminGao; Gay, S., 'Characterization of electric motor drives for traction applications, *Industrial Electronics Society, 2003*', *IECON '03. The 29th Annual Conference of the IEEE*, vol. 1, pp. 891-896
- [4] Minghui Hu, HongjunXie, Chunyun Fu, 'Study on EV transmission system parameter design based on vehicle dynamic performance', *International Journal of Electric and Hybrid Vehicles* - Vol. 6, No.2 pp. 133 – 151,2014
- [5] Paul D. Walker, Abdul Rahman Salisa, Bo Zhu, Nong Zhang, 'Modelling and optimisation of pure electric vehicle powertrains: a comparison of single and two speed transmissions', *International Journal of Vehicle Performance* - Vol. 2, No.1 pp. 85 – 102,2015
- [6] Han-Sang Jo, Yeong-Il Park, Jang-Moo Lee, Hyeoun-Dong Lee, Seung-Ki Su, 'A development of an advanced shift control algorithm for a hybrid vehicles with automated manual transmission', *International Journal of Heavy Vehicle Systems* Vol. 7, No.4 pp.281 – 298,2000
- [7] Xue, X.D, Cheng, K.W.E.; Cheung, N.C., 'Selection of Electric Motor drives for Electric Vehicle', *Power Engineering Conference, 2008. AUPEC '08. Australasian Universities*
- [8] Huang Ying, ShiXianlei, XuShili, ZhangFujun, GeYunshan 'Design of Gear shifting rules on the basis of Power Performance and Fuel economy and Experimental Study on Them', *Automobile Technology*, 2004-11
- [9] Ping, C., 'Shift-time Limited Acceleration: Final Drive Ratios in Formula SAE,' *SAE Technical Paper 2004-01-3554*doi:10.4271/2004-01-3554,2004
- [10] Rahman, Z., Ehsani, M., and Butler, K., "An Investigation of Electric Motor Drive Characteristics for EV and HEV Propulsion Systems," *SAE Technical Paper 2000-01-3062*, doi:10.4271/2000-01-3062,2000.
- [11] Ge Anlin, Shen Bo, 'Study on AMT Gear shifting behaviour', *Automobile Technology*, 2003-2.2003
- [12] Hamid TeimourianSefideh Khan, Saber Tavakoli, Ali Alavizadeh, 'Externally Electro-Pneumatic Shifting System (E.P.S) to Install on Manual Transmissions', *SAE Paper No 2012-01-1994*
- [13] Ann Holmes, Rony Argueta, 'A Technical Research Report: The Electric Vehicle' from http://www.writing.ucsb.edu/faculty/holms/Writing_2E-_EV_Technical_Research_Report.pdf
- [14] *Pneumatic Application & Reference Handbook*, © Copyright 2011 Bimba Manufacturing Company. RH-112 Effective January, 2012.
- [15] Qin Datong, Wang Yuhan, Hu Minghui. Power Train Parameter Design for the Electric Vehicle Considering Driving Cycle[J]. *Journal of Chongqing University*, 37(1): 7-14,2014
- [16] ChetanKumaarMaini (2005), 'REVA Electric car: a case study of innovation at RECC', *International Journal of Technology Management* - Vol. 32, No.1/2 pp. 199 – 212.2005
- [17] Electric Cars, 'electric-motor-gas-engine-torque.png'. Retrieved from <http://www.explainthatstuff.com/electriccars.html>