Development of Actuator Control Strategy for DC Motor Controlled Automated Manual Transmission (AMT)

Makarand S Kumbhar, Dhananjay R. Panchagade, Kapil Baidya

Abstract*: An Actuator control strategy for Automated manual transmission (AMT) which uses electro mechanical Dc motor controlled linear actuators is presented in this paper. The actuator control strategy decides the operation of actuators to achieve the desired gear shift as per command of Transmission Control Unit (TCU). The gear shifting control strategy decides on which gear to be chosen whereas the actuator control strategy decides how to achieve the gear selection by controlling the actuators. The actuator control strategy for vehicle Startup and running conditions are described with the help of algorithms. The developed actuator control strategy was implemented in software in loop analysis by using Matlab / Simulink based AMT driveline model in vehicle simulator called ADVISOR. The simulation result evaluates the developed actuator control strategy in terms of improved efficiency as compared to manual transmission (MT) for same drive cycle.

Index Terms*: Actuator, Algorithm, AMT, Control strategy.

I. INTRODUCTION

In today's automotive scenario, the AMT system has proven to be low cost and fuel efficient. An efficient shift process is based on the optimized actuator operation. It is important to improve the shift quality and reduce the torque interruption in AMT system by proper control of actuators. In important to improve the shift quality and reduce the torque interruption in AMT system by optimized control of actuators. In electro mechanically controlled AMT system, shift schedule is based on main gear shift control strategy which determines the target gear and this target gear is achieved by actuator control strategy. The final shift process is result of combination of gear shift strategy and actuator strategy which improves the efficiency of vehicle. The actuator control strategy varies with the number and type of actuators used in AMT system.

Many researches on AMT Drive train modeling and control have also been carried out. In studies devoted to gear shift control [1], considered reduced-order driveline models, clutch and gearbox actuator dynamics have been described by simple models or have been neglected. A high order dynamics of AMT System using hydraulic actuators was described in studies to optimize the performance of system [2]. Gear shifting strategy based on engine working conditions and driver intention was developed using fuzzy logic [3]. By using engine control during gear shift, a MT can be automated without using clutch during a shift event was showed in [4]. Most of the research work is based on gear shifting strategies with application on hybrid vehicle using AMT.

The objective of this paper is to develop an actuator control strategy and to evaluate its performance for AMT system consisting of electro-mechanical linear actuators for clutch, rank selection and gear shift operations which are Dc motor controlled. The clutch actuator is connected to clutch lever whereas rank and gear shift actuators are connected to gear shift levers. The wear of synchronizers can be addressed easily by changing the stroke lengths of actuators as required.

II. THE AMT SYSTEM CONFIGURATION

Fig. 1 shows the system configuration of Dc motor controlled AMT. It consists of sensors, processors and actuators. The processor, TCU (Transmission Control Unit) gets the input signals from various sensors like gear position sensor, clutch position sensor, brake position sensor, transmission output speed and also engine management based signals like torque requirement, engine speed and throttle position from ECU (Engine control unit) along with driver shift intention commands. The TCU has a gear shifting control strategy and an actuator control strategy which on receiving the various input signals generates the desired gear shift operation. The gear shifting control strategy decides on which gear to be chosen whereas the actuator control strategy decides how to achieve the gear selection by controlling the actuators.

For downsizing, weight and cost reduction DC motor based linear actuators are used. DC motor requires H-Bridge circuitry. The H-Bridge circuitry receives the command signal from TCU and controls the linear actuators. The software for microcontroller is developed in such way that it gives PWM signals to the driver IC. The analog feedback signals from actuators are given to the microcontroller in H-Bridge circuitry to analyze and control linear movement of actuator. ADC (Analog to Digital converter) of microcontroller reads this analog value. It is worth noting that present gear is detected based on feedback voltage and stroke length index values of all three actuators.

Revised Manuscript Received on 30 March 2014.
* Correspondence Author
Mr Makarand S Kumbhar*, PG Student, D. Y. Patil College of Engineering, Akurdi, Pune, India.
Dr. Dhananjay R. Panchagade, Head of Department of Mechanical Engineering, D. Y. Patil college of Engineering, Akurdi, Pune, India.
Mr. Kapil Baidya , Assistant General Manager , TATA MOTORS Ltd., India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

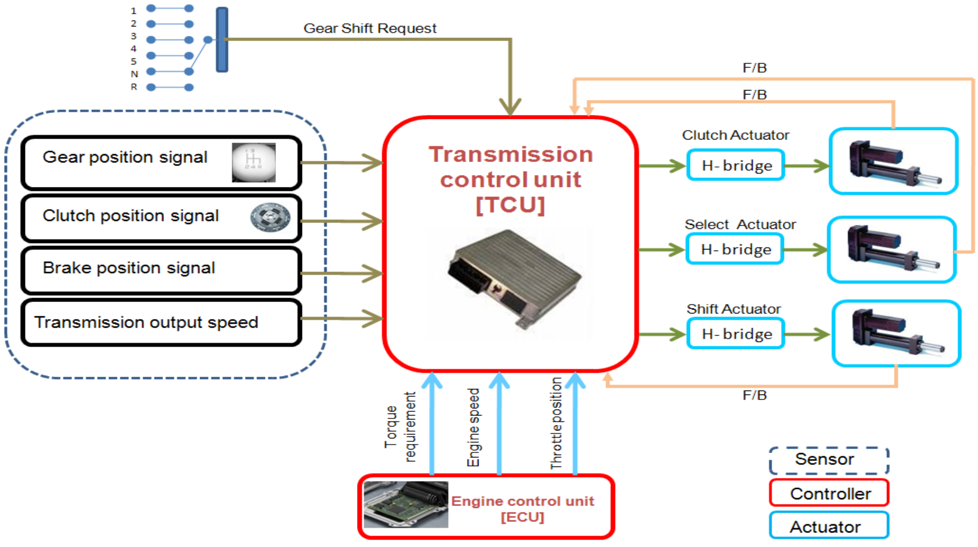

Figure 1: Dc motor controlled AMT system configuration

III. ACTUATOR CONTROL STRATEGY

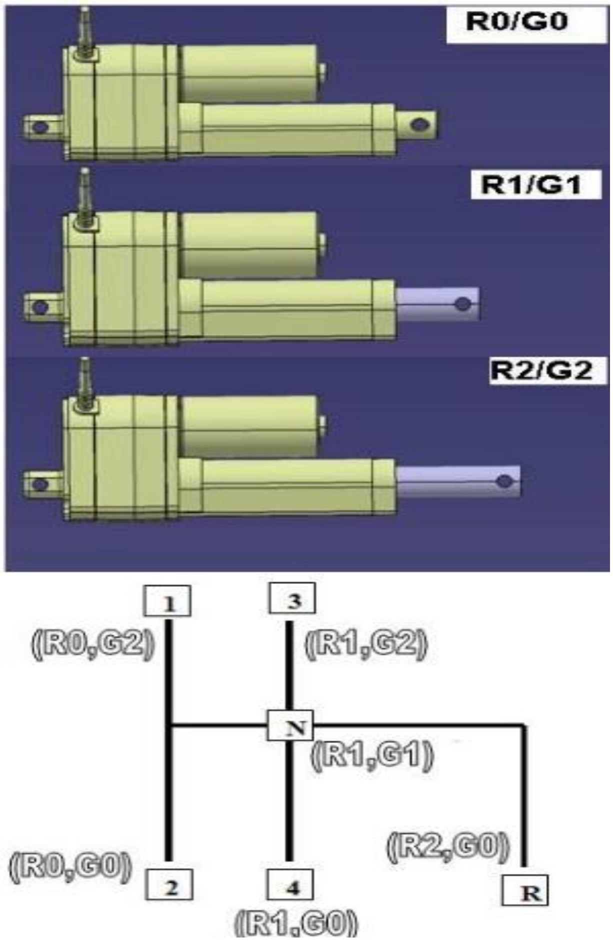

Figure 2: Indexed Positions of Gear and Rank actuators for gear selection.

Actuator control algorithm was designed for vehicle startup condition and vehicle running condition for a 4 speed AMT. The actuator control strategy helps in carrying out gear change by controlling the DC motor of all three actuators simultaneously based on inputs in the form of PWM signals.

The indexed positions on the motors are found using encoders. These positions act as markers for the movement of the motors. The clutch actuator is indexed at eight positions. Partial clutching is required during startup and incline drop situations. In all other conditions a flag is raised by the clutch when clutch is fully disengaged. The flag acts as a marker for the gear actuator to shift the selection to neutral. This helps in reducing the output shaft speed to enable jerk free shifting which is coordinated by Engine speed control with help of TCU. Similar to the clutch actuator, the gear actuator has three indexed positions which correspond to G0, G1 and G2 gear positions as shown in Fig 2. The gear actuator raises a flag when it comes to neutral to allow the rank actuator to select the next gear junction in the gear path. The rank actuator which is also indexed by three positions R1, R2, and R3 as shown in Fig 2 raises a flag at the end of movement to initiate the gear actuator which selects the required gear. Ranks are classified as Rank1 with 1st and 2nd gear, Rank 2 with 3rd and 4th gear whereas Rank 3 with reverse gear. Function of Rank actuator is to select between ranks from 1 to 3 and function of gear shift actuators is to choose gears for corresponding selected rank. The indexed positions of actuators are based on linear relation between actuator stroke length in mm and feedback Voltage of Dc motor. This means that stoke length of actuator is controlled by voltage value of Dc Motor. The actuator control strategy for vehicle startup and running condition are described as follows:

A. Actuator Control strategy for Vehicle startup

The objective of this actuator control strategy is to bring the vehicle to neutral gear before it is cranked and to initialize gear shifting process after engine is cranked with the help of gear shifting strategy. The process starts as driver puts the vehicle on KEY ON mode. It should be noted that during vehicle startup condition the engine is in off mode and hence the gears can be shifted without clutch operation. The main flowchart is divided into smaller phases for better representation. The following steps describe the main flowchart as shown in Fig. 3

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

The first step after driver puts vehicle in Key ON mode is to check whether vehicle is in neutral gear.

1) If the vehicle is in neutral gear and if accelerator pedal is pressed, the Engine control unit (ECU) is instructed to restrict the engine cranking whereas in case of accelerator pedal depressed, ECU allows engine to crank. This step is to stop engine from cranking with acceleration demand. If Engine is cranked after this safety check, the predefined gear initialization process is initiated which is based on gear shifting strategy.

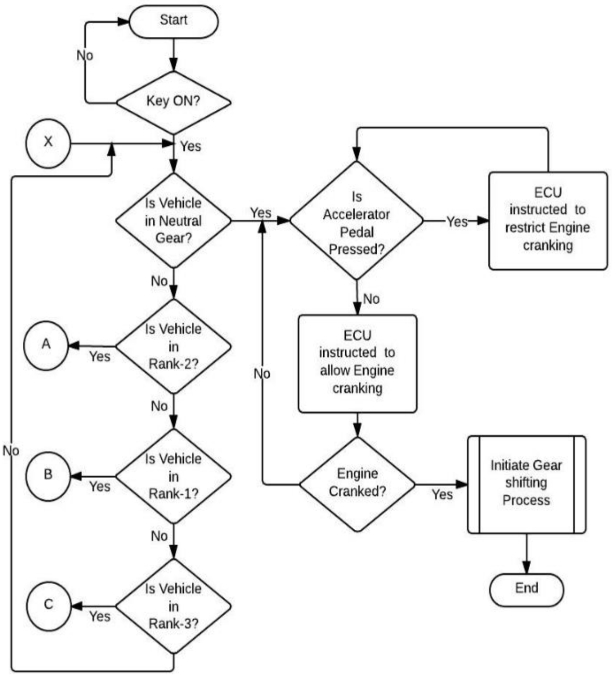

Figure 3: Main Flowchart for vehicle Startup Condition

2) If vehicle is not in Neutral gear, the current gear is identified and vehicle in brought to neutral gear followed by process as described in step 2. The detailed steps are explained as follows

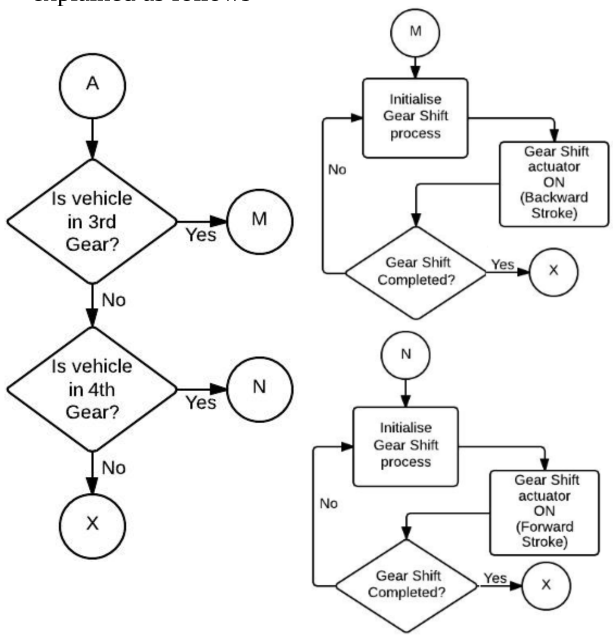

Figure 3(a): Sub Flowchart of vehicle Startup Condition for Rank 2

First step is to check whether vehicle is in Rank 2 i.e. to check whether it is in 3rd or 4th gear. The detailed process in this step as shown in Fig 3(a) is described as follows

If vehicle is in 3rd gear, the gear shift actuator actuates in backward stroke (G2 to G1as shown in Fig. 2) to bring vehicle in Neutral gear followed by feedback check to verify actuator has completed the shift action. If shift action is completed the process is send at X node as shown in Fig 3 to follow the process again as described in steps 1 and 2.

If vehicle is not in 3rd gear, it is checked for 4th gear and if vehicle is in 4th gear ,the gear shift actuator actuates in forward stroke (G0 to G1as shown in Fig. 2) to bring vehicle in Neutral gear followed by feedback check to verify actuator has completed the shift action. If shift action is completed the process is send at X node as shown in Fig 3 to follow the process again as described in steps 1 and 2.

If vehicle is not in 3rd and 4th gear, the process is started again from node X as shown in Fig. 3

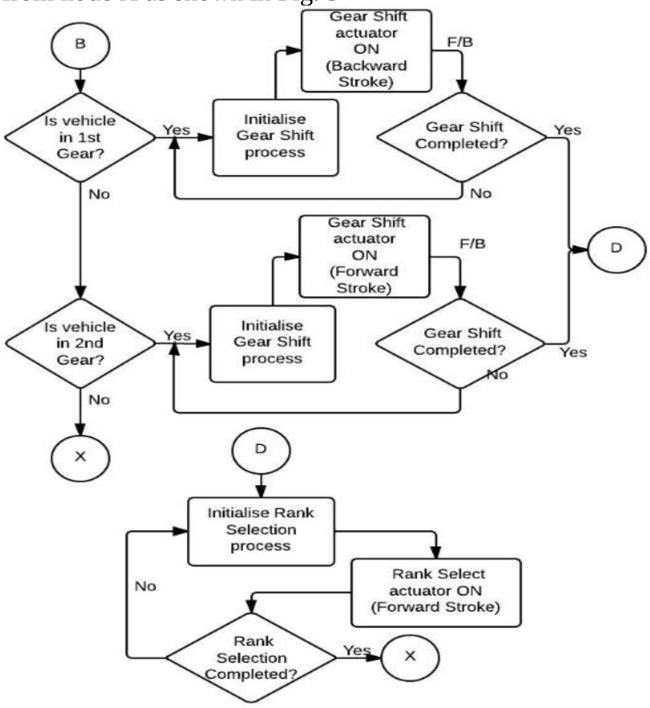

Figure 3(b): Sub Flowchart of Vehicle startup condition for Rank 1

If the vehicle is not in Rank 2, it is checked for Rank 1 i.e. to check whether it is in 1st or 2nd gear. The detailed process in this step as shown in Fig 3(b) is described as follows:

If the vehicle is in 1st gear, the gear shift actuator actuates in backward stroke (G2 to G1) as shown in Fig. 2 followed by feedback check to verify actuator has completed the shift action. If shift action is completed, the rank actuator actuates in forward stroke (R0 to R1as shown in Fig. 2) to set vehicle in neutral gear followed by feedback check to verify actuator has completed the rank selection action. If the rank selection action is completed the process is send at X node as shown in Fig 3 to follow the process as described in Steps 1 and 2.

If vehicle is not in 1st gear, it is checked for 2nd gear and if vehicle is in 2nd gear, the gear shift actuator actuates in forward stroke (G0 to G1as shown in Fig. 2) followed by feedback check to verify actuator has completed the shift action. If shift action is completed, the rank actuator actuates in forward stroke (R0 to R1as shown in Fig. 2)

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

to set vehicle in neutral gear followed by feedback check to verify actuator has completed the rank selection action. If the rank selection action is completed the process is send at X node as shown in Fig 3 to follow the process again as described in steps 1and 2.

a) If the vehicle is not in Rank 1, it is checked for Rank 3 i.e. to check whether it is in Reverse gear. The detailed process in this step as shown in Fig 3(c) is described as follows:

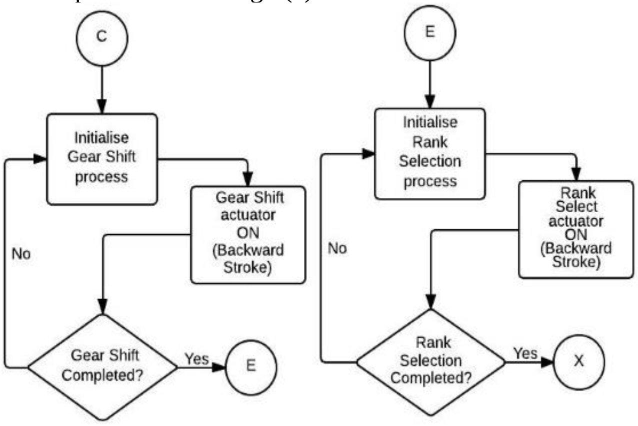

Figure 3(c): Sub Flowchart of Vehicle startup condition from Rank 3

b) If vehicle is in reverse gear, the gear shift actuator actuates in forward stroke (G0 to G1as shown in Fig. 2) followed by feedback check to verify actuator has completed the shift action. If shift action is completed, the rank actuator actuates in backward stroke (R2 to R1as shown in Fig. 2) to set vehicle in neutral gear followed by feedback check to verify actuator has completed the rank selection action. If the rank selection action is completed the process is send at X node as shown in Fig 3 to follow the process again as described in steps 1 and 2

B. Control strategy for Vehicle running condition.

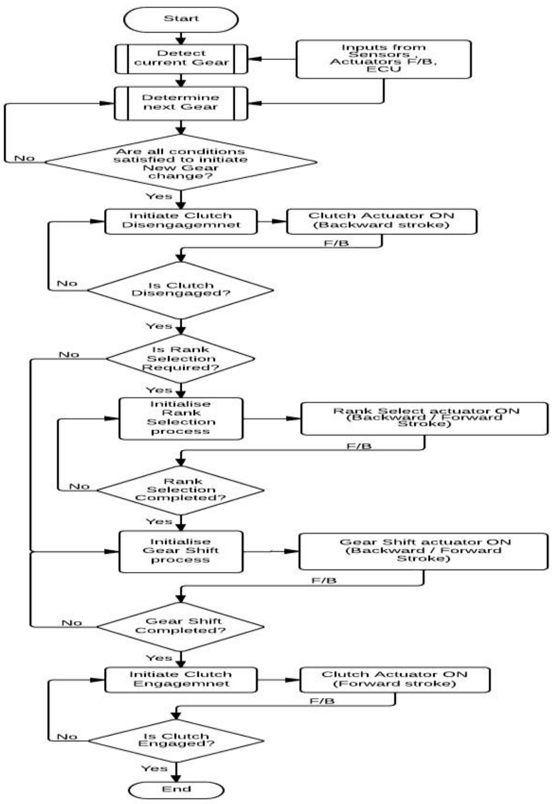

Figure 4: Main Flowchart for vehicle Running Condition

The objective of this actuator control strategy is to carry out gear shift process when the vehicle is in running mode. The flowchart show in Fig 4 has been combined to show various selection processes of actuators in simple manner. The steps involved are explained as follows:

1) The first step is pre defined process to identify the current gear in which the vehicle is running. The current gear is identified by the feedback signals from actuators, sensors, vehicle parameters like Vehicle speed, Engine rpm, throttle position etc. from ECU.

2) Once the current gear is identified the next possible gear is determined by Gear shifting strategy.

3) If all conditions for gear shift are satisfied like minimum engine Rpm, throttle demand etc then gear shift process is initiated. The conditions are defined such that gear shift will be of optimum nature.

The gear shift process begins with disengagement of clutch with backward stroke of clutch actuator followed by feedback check to verify the actuator has completed the required action

Next step is to check whether rank selection is required for selecting new gear. This step is necessary to check if current gear and new gear Rank are same. If Rank is not same then rank selection is initiated depending on new gear followed by feedback check to verify actuator has completed the rank selection. If Rank is same the gear shift process is initiated directly as in next step.

Once the rank is selected or already same as new gear, the gear shift process is initiated according to new gear followed by feedback check to verify actuator has completed the select action.

Last step is clutch engagement with forward stroke of clutch actuator followed by feedback check to verify the actuator has completed the required action and the new gear is selected.

The actuator control strategy was built in Matlab with the help of above algorithms. The actuators are indexed based on the stoke lengths and corresponding voltage feedbacks. Clutch actuator has eight position indexed as the clutch engagement process varies with engine speed and torque. Clutch actuator Voltage index = [0 0.48 0.655 1.2 1.6 1.84 2.15 2.86] volts. Clutch actuator stroke length index = [0 10 20 30 40 50 60 70] mm. Similarly Rank actuator is indexed for three positions (R0, R1, R2). Rank actuator Voltage index = [0 2.1 4.1] volts. Rank actuator stroke length index = [0 18 36] mm. Gear actuator is also indexed for three positions (G0, G1, G2). Gear actuator Voltage index = [0 2.5 4.6] volts. Gear actuator stroke length index = [0 24 48] mm. Fig 5 shows the State flow model developed in Matlab for actuator control strategy which is based on indexed values as stated above and is described as follows

1) The main gear change state starts with clutch actuator state with input values from Gear shift strategy in form of clutch index, idxc and Clutch actuator final voltage. During this state the clutch actuator is controlled for clutch disengagement and engagement process which is stated by ClutchActPin[idxc].

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

2) If the Clutch is disengaged, the gear actuator state is activated. ActuationCheck function confirms whether the actuator has completed the required action. The gear actuator stroke direction is determined from ActDir function based on desired and feedback voltages. The gear actuator is controlled by GearActpin [idxg].
3) The next state to be activated is Rank actuator state where in rank selection is done as per new gear desired. The rank actuator is controlled by GearActpin[idxg]
4) After rank selection, the gear actuator state is again activated to select new gear followed by clutch actuator state activation for clutch engagement to complete the gear change process.

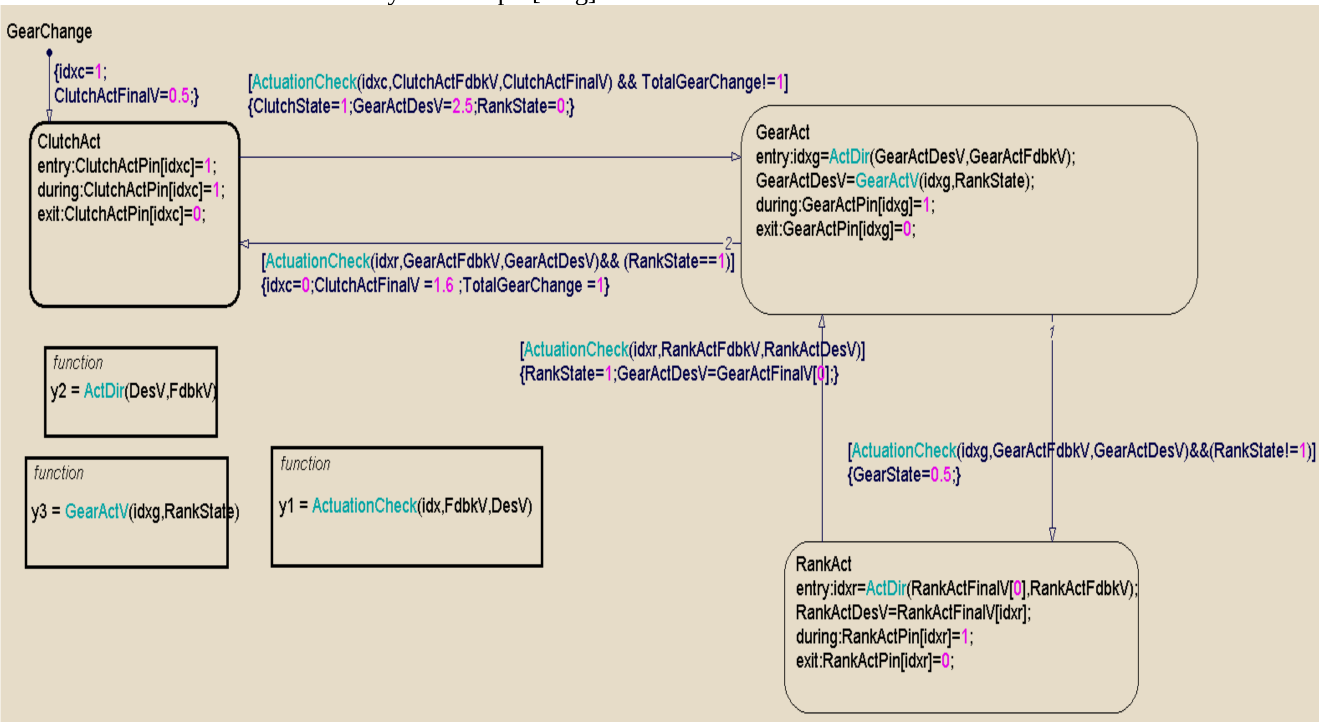

Figure 5: State flow for Actuator Control strategy

IV. SIMULATION RESULT

The developed actuator control strategy was implemented with build in AMT vehicle model which had conventional gear shift strategy in Advisor, the vehicle simulator software. Receiving the vehicle speed-time history as input, the simulation works backwards and calculates motion parameters as outputs. The vehicle subsystems in the simulation include engine, clutch, gearbox, differential, wheels, and axles of a default small passenger vehicle with 1400 kg vehicle mass and SI engine. Simulation was carried out on BS-IV Indian drive cycle as shown in Fig. 6 (Urban part) for developed actuator control strategy based AMT. The simulation was also carried out on Manual Transmission (MT) based inbuilt model with same configuration for efficiency evaluation.

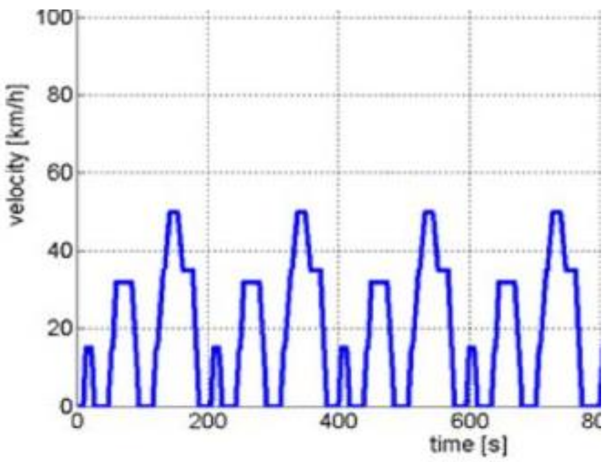

Figure 6: BS-IV urban part drive cycle

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved

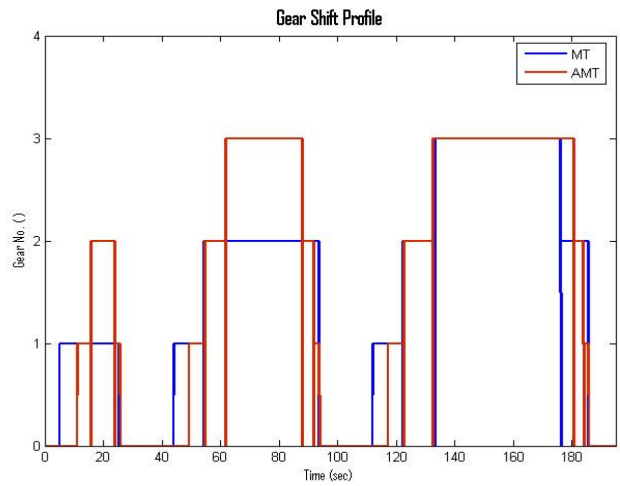

Figure 7: Gear shift pattern for AMT and MT

The simulation results indicates the successful execution of developed actuator control strategy which can be seen by optimized gear shift pattern as compared to MT as in Fig.7. The result also shows the fuel efficiency achieved due to optimized shift patterns of ATM over MT as shown in Fig. 8. The Simulation results indicated a fuel efficiency rise of 5 % as compared MT. The result also indicates that AMT is most beneficial in urban driving conditions due to less torque interruption during gear shift as compared to MT. It is worth to note that the efficiency achieved is combined result of developed actuator control strategy and in built gear shift strategy. The simulation result can be further refined and improved by optimization the control strategy for gear shifting.

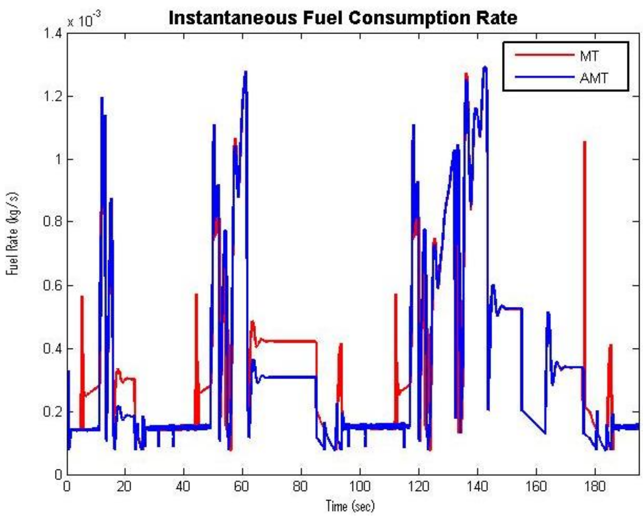

Figure 8: Fuel consumption rate for AMT and MT

V. CONCLUSION

An actuator control strategy was developed for Dc motor controlled Linear actuator based AMT. The actuator control strategy was developed based on algorithm for vehicle startup and running conditions. The simulation carried out in Advisor software demonstrated the working of developed actuator control strategy and evaluated its performance based on the fuel efficiency as compared to MT. The results showed a 5% fuel efficiency over MT and optimized gear shift patterns.

It is should be noted that the actuator control strategy needs to be developed further by considering hill hold functions as well. The actuator control strategy along with gear shift control strategy should be further optimized to reduce the shocks during gear shift process and to reduce the torque interruption during gear shifts. A more refined control is required over clutch engagement to reduce the jerks after gear shifting.

REFERENCES

1. Magnus Pettersson and Lars Nielsen, "Gear Shifting by Engine Control," IEEE transactions on control systems technology, vol. 8, no. 3, pp. 495-507, 2000.
2. Lucente, Marcello Montanari, Carlo Rossi and G. Lucente, "Modeling of an automated manual Transmission system," Mechatronics, vol. 17, pp.73–91, 2007.
3. B Mashadi, A Kazemkhani and R Baghaei Lakeh, "An automatic gear-shifting strategy for manual transmissions," IMechE, Systems and Control Engineering, vol. 221, pp.757-758, 2007.
4. Liao Chenglin, Zhang Junzhi, Zhu Haitao, "A Study of Shift Control Algorithm without Clutch Operation for Automated Manual Transmission in the Parallel Hybrid Electric Vehicle," Society of Automotive Engineers of China, Fiesta, World Automotive congress, Barcelona, February 13, 2000.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.