Shift Quality of Automated Manual Transmission: A Literature Review

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Abstract- *In last few years, automobile manufacturers are improving performance of transmission system thereby improving gearshift quality. This also includes reducing the amount of clutch operations and repeated gear shifting efforts in manual transmission. Automated manual transmission systems are developed which has advantage of both MT and AT. They are more efficient than manual transmission and less costly than automatic transmission. With improving technology towards refinement, gearshift quality has become one of the most important design criteria for any transmission system, which will reduce efforts for changing gears and ensure smooth transmission without torque interruption. Gearshift quality is the perception of gearshift felt by the driver. It is primarily decided by synchronizers in the transmission that function as a friction clutch and comes into action when vehicle operator needs a ratio change. The main aim of this paper is to study the various research work done on improving the shift quality of manual as well as automated manual transmission.*

Keywords- Automated Manual Transmission (AMT), Gearshift quality, Synchronizer

I. INTRODUCTION

The transmission system is one of the main parts that determines the behaviour, power and fuel economy of a vehicle. For maximizing fuel economy and minimizing emissions, it is recommended to perform the integrated control of engine, motor and transmission by using an automated transmission. In present days, several automated transmissions are developed such as an Automatic Transmission (AT), a Continuously Variable Transmission (CVT), and Automated Manual Transmission (AMT) etc. However there are some limitations to apply an AT and a CVT for light commercial vehicles. AT has the disadvantage of a large amount of power loss as its capacity is increased. In the case of AMT however, it is easily realized by mounting pneumatic actuators and sensors on the clutch and shift levers of the conventional manual transmission, and it reveals a high efficiency compared with AT.

The gear shift quality is a main concern for all vehicle manufacturers. It is observed that the quality of gearshift is a very important parameter in the perception of how good or bad the vehicle transmission is. In general, the driver only notices shift quality when it is poor. With poor shift quality driver efforts are increased and it may affect his driving performance. Shift quality is the perception of gearshift felt by the driver. Hence this perception varies from person to person. Factors that determine the quality of the shift are synchronizer selection, gear ratio, space constraints, inertia of rotational components, performance expected, transmission fluid used, shift feel of the shift mechanism and working environment. Gearshift quality is primarily decided by synchronizers in the transmission that function as a friction clutch and comes into action when vehicle operator needs a ratio change. [7]

II. LITERATURE REVIEW

A. **In Synchronizer Design**:A Mathematical and Dimensional Treatise by Syed T. Razzacki the physical parameters of synchronizer and their calculations are described. A synchronizer is a friction clutch which synchronizes the rotational speed of the transmission output shaft and the gear to be engaged allowing smooth gear change. Break Through Load (BTL) effectively sets the blocker ring into block position. The axial distance from sleeve tooth pointing to the blocker ring tooth pointing contact is called proximity and is dealt at length in the dimensioning and tolerancing section. The cone torque is primarily a function of the axial force applied to the sleeve, the cone angle, the surface coefficient of friction, and active cone diameter. When the synchronizer ring is indexed and the sleeve has traversed the proximity distance the sleeve pointing contacts the blocker ring pointing and a friction force is generated between the two chamfers. This friction force is in the direction of pointing angle resulting in torque which is known as index torque. [1]

B. Shifter Fork Stiffness Correlation to Gear Shift Quality by Singh, J., Verma, A., Kunal, R., Balpande, A. et al. describes a correlation between stiffness of the shift fork and gear shift quality in manual transmission. This paper concentrates on using GSQA hardware on 5 speed manual transmission and correlating the results obtained through different iterations of varying stiffness obtained from Fork stiffness analysis in MSC NASTRAN. The gear shift quality is measured using a gear shift quality assessment setup. Gear shift quality is defined by various factors like gate definition, shift effort, second load, double bump, fork stiffness and vehicle response. This paper also illustrates the phenomena of the deflection that must occur in the elastic deformation zone of the fork material.

The gear shift fork stiffness optimization relates to the deflection of the shift fork prongs attached to the gear shift rail support. The gear shift fork undergoes a deflection when the synchronization force is applied to it. The two gear shift prongs in the same gear shift fork can have different stiffness or can have same stiffness. The difference in the behavior of the gear shift fork stiffness is attributed to the position of the gear shift rail with respect to the gear shift fork pads or to the symmetricity of the gear shift fork. If the gear shift fork is symmetrical then the stiffness of the prongs would be equal. If not the stiffness has to be optimized so that both the prongs of the gear shift fork comes into contact with the synchronizer sleeve at the same time during synchronization i.e. should have similar deflections. Gear shift fork Stiffness = (Parameterization force/2) × Gear shift pad deflection, i.e. the parameterization force could be the synchronization force or the regular gear shift force or the abusive gear shift fork. [2]

C. S Krishnan in his paper Gear Shift Quality Benchmarking for Manual Transmissions explains the benchmarking from the synchronizer design perspective of a newly developed truck transmission. This paper describes the functions and features of synchronizer system. The cone torque should be always more than the index torque. Chamfer angles that are low result in clash and high chamfer angles result in blocking and hard shifting. The higher sleeve chamfer angle in the gear cone assembly results in damage to the ring chamfers and hard shifting. Shift effort and index torque increases with the increase in cone angles. Cone torque is directly dependant on coefficient of friction between ring and cone. The shift effort is predicted over a range of synchro time of 0.75 to 1.5 seconds. The shift effort reduces with the increase in syncronising time. The shift effort calculated at the hand ball is with the efficiency and leverages.[3] The parameters calculated for benchmarking are as follows:

- Rotational Inertia: $I_n = MK^2$
  Here M = Mass, K = Radius of Gyration
- Angular Acceleration: $f = (w_2 - w_1) / t_s$
  Here f = Angular Acceleration
  t_s = Synchro time in seconds
  w_1 = Rotational speed of present gear
  w_2 = Rotational speed of gear to be synchronized.
- Reflected Inertia:
  $I_{Ref\,B} = I_B + (N_B/N_{C'})^2 [I_C + (N_{C'}/N_A)^2 (I_A + I_D)]$
  Here I_A, I_B, I_C, I_D = Rotational inertias of each component
  N_A, N_B, N_C, $N_{C'}$ = No. of gear teeth on each gear resp.
- Cone Torque: $T_C = I_R f$
  Here T_C = Cone torque, I_R = Reflected rotational inertia
  f = Gear acceleration
- Index Torque: $T_I = R_B F_T$
  Here F = Axial Sleeve Force
  RB = Blocker Ring Chamfer Pitch Radius
  B = Chamber included Angle
- Axial Sleeve Force: $F = T_C \sin\phi / \mu_C R_C$
  Here T_C = Cone Torque
  F = Axial Sleeve Force
  μ_C = Dynamic Coefficient of Friction
  R_C = Mean Cone Radius
  Φ = Cone Angle
- Synchronizer Sleeve Force: $F_S = F_H K C_E - F_R$
  Here F_H = Hand Ball Load
  K = Mechanical Advantage
  C_E = Efficiency of Linkage and Synchronizer
  F_R = Resultant Force deviation between Synchronizer and Rails

D. Gear-Shift Strategy for a Clutchless Automated Manual Transmission in Battery Electric Vehicles by Liu, H., Lei, Y., Li, Z., Zhang, J. et al. shows that the AMT used in battery electric bus can remove the clutch. This is because the electric motor has excellent low speed control capability, so the vehicle can be launched by controlling motor smoothly and TCU can quickly control the motor from torque output mode to free mode before releasing gear. And at this moment, the motor is not excited or its output torque is very small; it is equivalent of cutting off the power between motor and transmission. So the actuators can pick at this time to finish the gear release operation. For these reasons, the clutch is abolished.

The function of synchronizer is to allow smooth engagement of gears during the gear engagement phase. On the one hand, the synchronizer makes the angular velocity completely equal between two engaging elements through friction torque produced by the friction elements; On the other hand, before the angular velocity of the two engaging elements achieves full equality, synchronizer generates the locking torque to prevent shift. Nevertheless, due to the abolition of clutch in battery electric bus, one engaging element is connected to the motor and the other one is connected to the driveshaft directly. Inertia of the two parts are both great. If we still use the friction energy of two friction elements to achieve synchronization, the synchronizer will be worn quickly and seriously and the shift time will take a long period. Thus this solution cancelled synchronizer and only employed sleeves to accomplish engagement of two gears. [4]

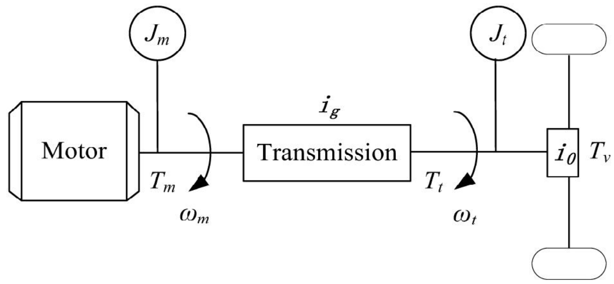

Fig. 1 Model of powertrain system for battery electric bus

E. In paper Development of an Objective Methodology for Assessment of Commercial Vehicle Gearshift Quality by Raunak Santosh and Vijayakumar Chekuri, the authors have made a comparative study of gear shift quality attributes in a set of intermediate commercial vehicles. They have also explained how, the subjectivity of human perception with regard to gearshift comfort can be captured through objective testing methods and correlated. Most of the times the critical importance is given to measuring the physical effort demanded from the driver when manipulating the lever to select and engage the desired gear. Synchronization time in each gear or total time taken for gear engagement is also used to measure quality. Sometimes shift forces and shift feel to the different phases of synchronization are also used. This paper describes how an objective methodology was developed, by performing static and dynamic measurements, based on detailed subjective assessments of three different intermediate commercial vehicles.

The two different methodologies described are subjective assessment and objective assessment. In subjective methodology, gearshift quality is assessed in different driving conditions and quality attributes are rated accordingly. In dynamic methodology, in-gear free plays and force required during selecting and shifting are measured. Gate definition is defined as the layout pattern for each gear position in the shifter system. In-Gear Freeplay can be defined as the voids that are present in the engagement position of each gear. Compliance Envelope is the envelope traced by the shift lever that should prevent the gear lever from entering into the space of adjacent gear positions. Cross Gate Selection can be defined as the feel of selection of different gates when moving the lever in the lateral direction. Shift feel may be defined as a measure of the smoothness of the shift, or how cleanly the lever moves into gear. Sense of shift pull out can be defined as the feedback of different phases while disengaging from any in-gear position. Sense of Shift into Gear can be defined as the feedback of different phases during a single shift. [5]

F. Shift Quality Improvement through Integrated Control of Dual Clutches Pressure and Engine Speed for DCT by Xiaofeng Yin, Yuan Zhong, Xiaohua Wu, and Han Lu investigated an integrated control strategy for the gear-shift process that takes into account the influences of oil pressure of dual clutches and engine speed on shift quality. This paper describes evaluation indices and factors influencing the shift quality. The authors describe factors like shift time, shift jerk and friction work with mathematical expressions. In the gear-shift process, regulating the engine speed to make it quickly synchronize with the speed of the clutch of the target gear position can shorten the shift time and also reduce the friction work. If the target oil pressure acting on dual clutches could be regulated according to different gearshifts, it is possible to improve the overall shift quality. [6]

III. FUTURE SCOPE

Gearshift quality of 5 speed LCV with automated manual transmission needs to be improved. For analysis, parameters from existing synchronizer will be taken. Study of different components of transmission system like clutch, gear box, sensors and actuators will also be included. Actual gear shifting forces will be measured at hand lever. A physical model will be developed in MSC Adams for simulation at system level and depending on the result, optimization of shift quality will be carried out.

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