

# Assess, Analyse and Improve Shift Quality of Five Speed Automated Manual Transmission for LCV

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**ABSTRACT:** In most recent couple of years, vehicles producers are enhancing execution of transmission framework along these lines enhancing gearshift quality. This additionally incorporates lessening the measure of grip operations and rehased gear moving endeavours in manual transmission. Robotized manual transmission frameworks are created which has point of interest of both MT and AT. With enhancing innovation towards refinement, gearshift quality has ended up a standout amongst the most essential outline criteria for any transmission framework, which will decrease endeavours for changing riggings and guarantee smooth transmission without torque interference. It is fundamentally chosen by synchronizers in the transmission that capacity as a contact grasps and comes without hesitation when vehicle administrator needs a proportion change. The fundamental point of this paper is to get to, examine and enhance shift nature of five velocity robotized manual transmission for LCV. For examination, parameters from existing synchronizer and grip, gear box were utilized. Same was confirmed utilizing MSC Adams/View Software and handball power required to change the gears was lessened.

**KEYWORDS:** Gearshift quality, Automated manual transmission, Synchronizer

## I. INTRODUCTION

Transmission arrangement of a vehicle is that framework which transmits vehicle motor's mechanical energy to the wheels. Various types of transmission systems available today are Manual transmission (MT), Automatic Transmission (AT), a Continuously Variable Transmission (CVT), and Automated Manual Transmission (AMT). In manual transmission, grip withdrawal, gear moving and grasp engagement is physically done. These are the most effective transmission frameworks. In programmed transmission, the grip and apparatus work are finished by transmission liquids. These frameworks are heavier than manual ones, consequently are less proficient. Henceforth AMT was created which has favourable circumstances of both MT and AT. The gear shift quality is a fundamental sympathy toward all vehicle makers. It is watched that the nature of gearshift is a critical parameter in the impression of how great or awful the vehicle transmission is. All in all, the driver just notification shifts quality when it is poor. With poor movement quality driver endeavours are expanded and it might influence his driving execution. Shift quality is the view of gearshift felt by the driver. Thus this discernment changes from individual to individual. Elements that decide the nature of the movement are synchronizer determination, gear proportion, space limitations, dormancy of rotational segments, execution expected, transmission liquid utilized, shift feel of the movement component and workplace. Gearshift quality is principally chosen by synchronizers in the transmission that capacity as a grinding grasp and comes enthusiastically when vehicle administrator needs a proportion change.

## II. RELATED WORK

Manual Transmission Synchronizers by Richard J. Socin and L. Kirk Walters describes the design and working of synchronizers used in manual transmissions. Synchronizers, also called as small clutches, were developed to ease the process of selection of gears and prevent damage of gears. The various types of synchronizers are constant load cone,

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multicone and plate, servo and pin loading synchronizers. Performance of the synchronizer is measured by different parameters like synchronization time, cone torque, index torque, rotational inertia, reflected inertia, shift effort and shift comfort. Factors that affect the performance of the synchronizer include the design variables like cone angle, chamfer angle, proximity of ring, indexing, surface finish, coefficient of friction, etc. Coefficient of friction depends upon gear and ring material, lubricant, operating temperature, surface finish and slip speed. [1]

In Synchronizer Design: A Mathematical and Dimensional Treatise by Syed T. Razzacki the physical parameters of synchronizer and their calculations are described. It explains the synchronization process in six phases. This paper describes the need, functions and parts of synchronizers along with steps in synchronizing and the performance evaluation to benchmark a newly developed transmission with respect to an existing transmission of different torque capacity. 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. The significant synchronizer parameters which affect the synchronization process are Break Through Load, proximity, cone torque and index torque. [2]

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 in manual transmission. The synchronizer mechanism consists of various parts such as Engaging ring cone (gear cone), Synchronising cone, Interlock balls, Guide sleeve, Engaging sleeve, Engaging ring splines, Chamfers, Detent and Spring. The effect of various synchro parameters namely coefficient of friction, cone angle, blocker angle, synchro time on gearshift quality and performance of manual transmission is studied. For smooth transition of gears, the chamfer or blocker angle must be  $105 - 125^\circ$ . Parameters that affect the coefficient of friction are gear and ring material, lubricant, temperature and surface finish of gear cone. The gear box are rated on shift time and shift time is decided by synchronization time. Shift effort calculations include efficiency and leverages. This paper also gives the details of the mathematical relationships involved in the synchronizer operation. [3]

Sachin Agarwal presented the paper on "Optimization and Benchmarking of Heavy Duty Truck Transmission for Gear Strength, Shift Quality and Fuel Economy" which describes the optimization of a heavy duty truck transmission for performance parameters like fuel economy, gear strength, life and shift quality. Synchronization process was simulated with the help of a mathematical model by setting targets for shift time and effort. Synchro parameters were then optimized wherever required. Benchmarking at every stage of optimization has been in proper selection of optimization criteria and targets [4].

Aravindraj Alaguvel and Vijayakumar Chekuri in paper An Effective Way To Measure Manual Gearbox Synchroniser Performance have described the method to evaluate synchronizer performance of different transmissions and compared the same objectively and subjectively. In objective method, force required to change the gear and synchronization time are taken into consideration. In subjective method, the gear shifting attributes are rated by number of drivers and shift quality is rated upon that. A new term synchronization impulse was used in above methods. Synchronization impulse is the area under the force curve during synchronization. [5]

### III. SHIFT QUALITY AND SYNCHRONIZER

The impression of gearshift felt by the driver is called shift quality and it changes from individual to individual. It is watched that the nature of gearshift is an essential parameter in the view of how great or terrible the vehicle transmission is. A decent gearshift quality financially helps the driver as well as it accommodates a superior control and drivability. Variables that decide the nature of the movement are Synchronizer determination, Gear proportion, Space limitations, Inertia of rotational segments, Performance expected, Transmission Fluid utilized, Shift feel of the movement instrument and Working environment

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**Fig. 1: Synchronizer**

Synchronizers are those mechanical components that equalise the rotating gears while shifting from one gear to other. They will allow shaft sleeve and gears to engage only when their angular speed difference becomes zero. And this is done by the friction contact between the conical surfaces of gears and synchronizer ring. Parameters to calculate performance of Synchronizer Mechanism: [1]

1. Rotational Inertia:  $I_n = MK^2$   
It is the physical property of every rotating component.
2. Angular Acceleration:  $f = (w_2 - w_1) / t_s$
3. Reflected Inertia:  $I_{RefB} = I_B + (N_B/N_C)^2 [I_C + (N_C/N_A)^2 (I_A + I_D)]$   
It is inertia of parts multiplied by square of gear ratios.
4. Cone Torque:  $T_C = I_R f$   
It is the torque generated due to friction between cones of gear and synchronizer ring.
5. Index Torque:  $T_I = R_B F_T$   
It is the torque generated due to friction between chamfers of sleeve ring and synchronizer ring.
6. Axial Sleeve Force:  $F = T_C \sin\phi / \mu_C R_C$
7. Synchronizer Sleeve Force:  $F_S = F_H K C_E - F_R$
8. Synchronization Time:  $t_s = (w_2 - w_1) / (T_C \pm T_D)$

#### IV. HANDBALL FORCE CALCULATION

Handball force require to shift the gears were first measured on existing system. This force is then compared to analytical calculations done later. To measure this handball force, a strain gauge was placed between the lever and the handball. This was done using a suitable fixture. The sensor was Texense Gear Shift Device. The range of the sensor was  $\pm 250$  N and accuracy being 5%. Its output in terms of force was measured on ETAS MDA 4.1 software. The experimental setup was as given in fig. 2 and fig. 3.

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**Fig. 2: Sensor Position**

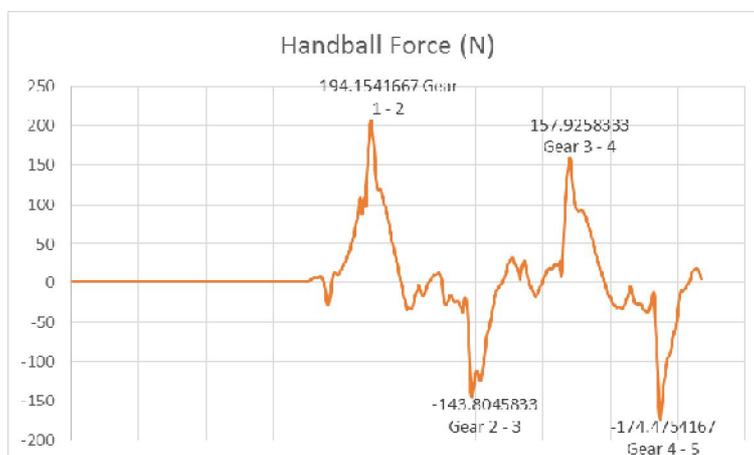
ETAS MDA is Measure Data Analyzer. It is used to display and analyse the measurement data in MDF or ASCII format. It has three views to display the measured data:

1. Graphical (YT and XY oscilloscope)
2. Tabular
3. Statistical



**Fig. 3: Experimental Setup to measure handball force**

The forces measured on ETAS MDA 4.1 software were as follows:



**Fig. 4: Forces obtained from ETAS MDA 4.1 software**

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After the gear is shifted, still force is exerted by the driver on lever for couple of seconds before he removes his hand. This force also get added up and can be seen in the above Fig. 4 Hence, even the force required to shift the higher gears looks more than required. Analytically the forces are calculated below. The synchro ring here is of brass alloy material. The gear cone is made up of steel. To include all the uncertainties, efficiency of the system is taken minimum (worst case is considered).

**Table 1: Synchronizer Data**

Cone Angle	7°
Cone Radius	0.039 m
Chamfer Angle	110°
Blocker ring radius	0.0475 m
Coefficient of Friction	0.08
Efficiency	0.65
Linkage Factor	5

**Table 2: Data of Gears**

Gears	On Main Shaft (Kg)	On Counter Shaft (Kg)
1	2.45	0.47
2	2.05	0.69
3	1.44	0.93
4	0.86	1.90
5	0.23	2.46

Using above details and equation (8), reflected inertial is calculated.

$$I_{Ref B} = I_B + (N_B/N_C)^2 [I_C + (N_C/N_A)^2 (I_A + I_D)] \dots\dots\dots (9)$$

**Table3: Reflected inertias of gears**

Gears	Gear Ratios	Reflected Inertia (kg-m <sup>2</sup> )	Change In Speed (rpm)	Angular Velocity (rad/s)	Angular Acceleration (rad/s <sup>2</sup> )
1 to 2	6.32	0.741	155.242	16.257	23.224
2 to 3	4.24	0.317	247.726	25.942	37.06
3 to 4	2.78	0.110	515.143	53.946	77.065
4 to 5	1.62	0.065	765.432	80.156	114.508

Analytically the forces were calculated as given below using equations (1) to (8). The vehicle speed was considered 2000 rpm.

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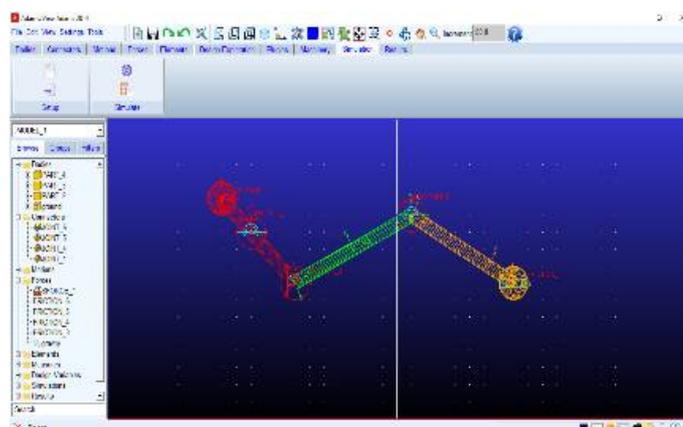
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**Table 4: Force Calculations**

Gears	Cone Torque (Nm)	Sleeve Force (N)	Handball Force (N)	Index Torque (Nm)	Clash Ratio
1 to 2	17.2090	672.1947	206.8291	13.5046	1.2743
2 to 3	11.7480	458.8857	141.1956	9.2191	1.2743
3 to 4	8.4772	331.1233	101.8841	6.6524	1.2743
4 to 5	7.4430	290.7295	89.4552	5.8408	1.2743

The handball forces were again verified in MSC Adams/View software. Adams/View helps us build models of mechanical systems and simulate the full-motion behavior of the models. We can also use Adams/View to quickly analyze multiple design variations until you find the optimal design. The gear shift lever modelled in MSC Adams/View Software is as follows:



**Fig. 5: Gear shift lever model in MSC Adams/View Software**

**Table 6: Forces calculated analytically and by MSC Adams/View**

Gears	Analytical (N)	MSC Adams/View (N)
1 to 2	206.8291	205.23
2 to 3	141.1956	150.50
3 to 4	101.8841	110.98
4 to 5	89.4552	99.46

As we have considered the worst case using efficiency of 65%, the calculated handball force and actual handball force doesn't match. This also because the measured forces include the losses which are not considered during calculations. But if we increase the efficiency to actual efficiency of system, then the values will come nearby to actual.

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## V. SHIFT QUALITY IMPROVEMENT

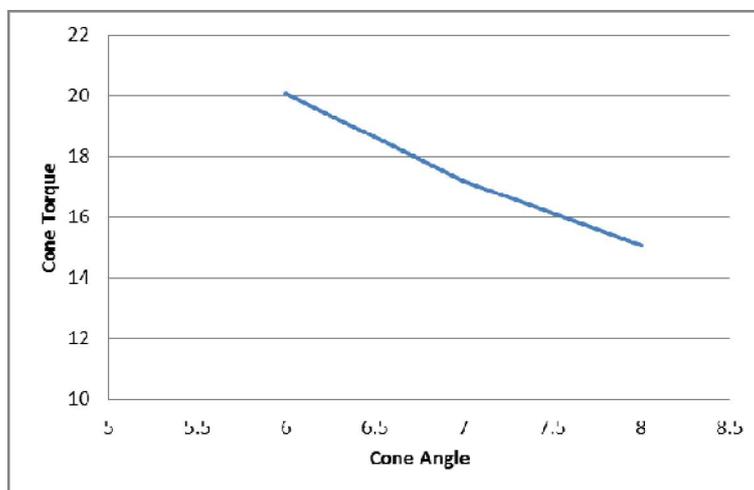
Here the gear set parameters will be kept same and shift quality will be improved only at synchronizer level. This can be achieved by reducing the index torque than cone torque thereby reducing handball force. The vehicle speed was considered 2000 rpm. The parameters which were varied for optimization were:

### 1. Cone Angle:

Cone angle of  $6^\circ$  to  $7^\circ$  is considered optimum for better shift quality. Here the cone angle is varied from  $6^\circ$  to  $8^\circ$  keeping other parameters constant. And cone torque is calculated. Cone torque will indirectly give the results for index torque, clash ratio and handball force.

**Table 7: Handball Force calculations by varying Cone Angle**

Cone Angle (Degree)	Cone Torque (Nm)	Index Torque (Nm)	Clash Ratio	Sleeve Force (N)	Handball Force (N)
6	20.063	13.5046	1.4857	576.5476	177.3993
7	17.208	13.5046	1.2743	672.1947	206.8291
8	15.069	13.5046	1.1159	767.6371	236.1960



**Fig 6: Cone Torque vs. Cone Angle**

It can be seen from the graph that with increase in the cone angle, there is decrease in cone torque. If the cone angle is reduced, the cone torque increases thereby increasing the chances of cone clutch to stick and seize. If the cone angle is increased, there will be reduction in cone torque thereby decreasing the clash ratio. Same was verified by MSC Adam/View as follows:

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**Table 8: Forces obtained from MSC Adams/View**

Cone Angle (°)	Analytical (N)	MSC Adams/View (N)
6	177.39	174.8
7	206.82	205.23
8	236.19	245.9

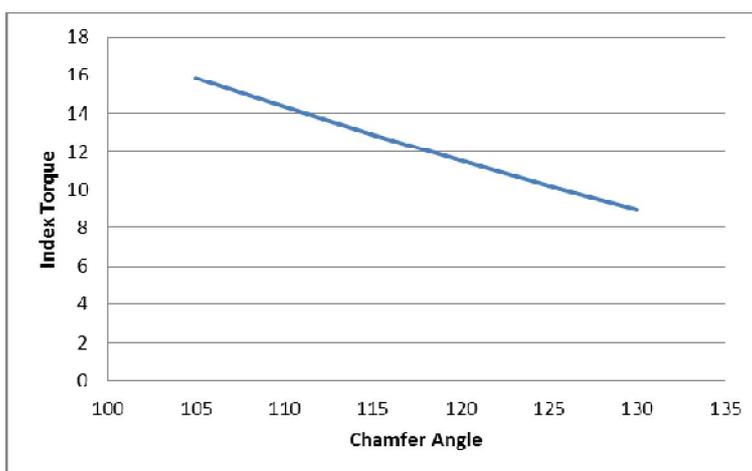
2. Chamfer Angle:

Chamfer angles are kept usually between 105° to 125°. Here the chamfer angles are varied from 105° to 130° keeping other parameters constant. Index torque is calculated with these chamfer angles. Index torque will give us the clash ratio by which shift effort can be determined.

**Table 9: Index Torque**

Chamfer Angle (°)	Index Torque (Nm)	Clash Ratio
105	15.83	1.09
110	14.33	1.20
115	12.90	1.33
120	11.53	1.49
125	10.21	1.69
130	8.94	1.92

Index torque is plotted against chamfer angle. Cone torque is opposed by index torque during synchronizing process, hence cone torque must always be higher than index torque to rotate the gear and sleeve in mesh. Therefore, cash ratio also must be higher than 1.0.



**Fig 7: Index Torque vs. Chamfer Angle**

From above graph, it can be seen that index torque decreases with increase in chamfer angle. Lower chamfer angles result in clash. This causes mechanical damage of the ring as well as gear teeth. Higher chamfer angles result in blocking of ring and thus results in hard shifting. From equations, cone and chamfer angle relationship can be determined by equating the cone and index torque. Assuming, static friction between chamfers equal to zero, we get,

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$$\tan \frac{\theta}{2} = \frac{RB \sin \phi}{R_c \mu c} \dots\dots (9)$$

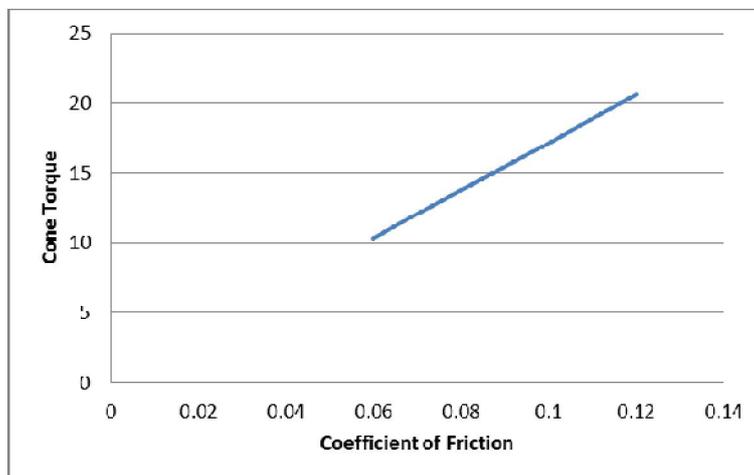
With existing cone angle and coefficient of friction, chamfer angle must be nearby 110°

3. Coefficient of friction:

Here the coefficient of friction is varied from 0.06 to 0.12 keeping other parameters constant. Cone torque, index torque and handball forces are calculated from this.

**Table 10: Handball Force calculations by varying Coefficient of Friction**

Coefficient of Friction	Cone Torque (Nm)	Index Torque (Nm)	Clash Ratio	Sleeve Force (N)	Handball Force (N)
0.06	12.91	14.26	0.91	896.26	275.77
0.07	15.06	13.88	1.08	768.22	236.38
0.08	17.21	13.50	1.27	672.19	206.83
0.09	19.36	13.13	1.47	597.51	183.85
0.1	21.51	12.76	1.69	537.76	165.46
0.11	23.66	12.40	1.91	488.87	150.42
0.12	25.81	12.04	2.14	448.13	137.89



**Fig. 8: Cone Torque vs. Coefficient Of Friction**

From above graph it can be seen that cone torque increases with increase in coefficient of friction between ring and gear material. Surface finish of cones plays an important role in determining the optimum coefficient of friction. It is advised to keep the finish between 2 to 12 microns. This will produce coefficient of friction from 0.06 to 0.10. Same was verified by MSC Adam/View. The handball forces are as follows:

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**Table 11: Forces obtained from MSC Adams/View**

Coefficient of Friction	Analytical (N)	MSC Adams/View (N)
0.06	275.77	251.7
0.07	236.38	234.4
0.08	206.83	205.2
0.09	183.85	189.7
0.1	165.46	165.8
0.11	150.42	150.3
0.12	137.89	138.1

## VI. RESULTS AND CONCLUSION

From the above results we can watch that, for the same parameters of rigging set, shift quality can be enhanced by expanding the chamfer point by 125°. It can likewise be enhanced by expanding the coefficient of erosion to 0.11, which likewise fulfils the cone and rubbing relationship expressed previously. Above coefficient of friction can be gotten if manufactured ring material is utilized with steel gear cone and within the sight of oil containing 6% zinc dithiophosphate. Cone torque of 7° is kept same as it is inside required points of confinement. To keep the seizure of synchronizer ring on rigging cone, the accompanying cone and erosion relationship is required.  $\mu_c \leq \tan\phi$ . With the above qualities, this condition is fulfilled. These alterations will decrease the handball power required.

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