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Improvement in Gear Shift Performance of Manual Transmission System

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Abstract: ***Fast growth in the Indian economy has steered to new market trends for commercial vehicles. In today's aggressive automobile market, customer expectations are very high, particularly in respect of comfort and quality. Gear shifting is vital interface between driver and vehicle, any inconsistency in gearshift performance can give rise to customer unsatisfactionresults into negative impression of brand image. Although every vehicle manufacturer is striving to improve gearshift performance "Double Bump" continued to be stress area in shift feel. The main objective of this work is to improve gearshift performance of North-South (N-S) transmission with help of variable parameters namely cable routing optimization, introduction of gear shift linkage inertia mass and introduction of shifter shaft detent profile. It also aims at finding correlation among variable parameters with help of Gear Shift Quality Assessment (GSQA) trough experimental analysis. This work consist of a number of tasks such as modelling of component, CAD simulation and series of GSQA test with the help of Ricardo software and hardware.***

Keywords: Double Bump, North-South (N-S) transmission,Gear shift linkage inertia mass,Shifter shaft detent profile, GSQ and CAD

1. Introduction

The importance of customer centricity, delightness has grown considerably in last decade due to continuously varying quality requirement enforced by automobile market. The shift feeling and comfort while driving is influencing factor, which decide overall impression of vehicle. Designer has to fulfill basic requirement ofgearshift, whichcan be roughly summarized by the following attributes: smooth, exact as well as noiseless and without vibrations.

Dynamic gearshift quality of a manual transmission is very crucial parameter, which is pure function of synchronizer. Achieving acceptable gearshift quality is challenging, as behavior of dynamic gearshift parameter during gearshift is highly nonlinear and random. Designing and dynamic behavior of synchronizer are most complex phenomenon in manual transmission. Behavior of most of dynamic and static parameters as pullout force, synchronization force, detent force and end stop force are predicted through calculation and they depend on synchronizer design and gearbox layout.

Double bump is most important parameter while considering shift comfort and most difficult to predict its dynamic event. Double bump or secondary force is force generated by hitting dog teeth of shifter sleeve to the dog teeth of synchro ring at the end of free flight. The double bump to synchronization force ratio should be less than 0.5 to achieve acceptable shift quality. Normal driver will not be able to feel double bump if double bump ratio is less than 0.6 [1].

For gearshift performance improvement most of the researchers have worked only on single parameter where as it should be studied considering the impact of all parameters together. Present work has been undertaken to study the influence of various parameters for combined effect.

This work involves various techniques to improve gearshift performance and its verification with experimental analysis, which were carried out with help of Ricardo software and hardware. Ricardo has developed tools and technique to establish good gearshift quality at initial or production stage. This work involve physical trials by changing variable parameter and study their effect on gearshift performance. Finally, gear shifterlinkage was updated with rubber damper and vehicle was offered to jury trials for subjective shift feel evaluation.

1.1 Synchronization Phases

The main objective of the work is to improve gearshift performance. This involves study of basics of synchronizers [2]. The different stages of synchronization process is shown in Fig-1.

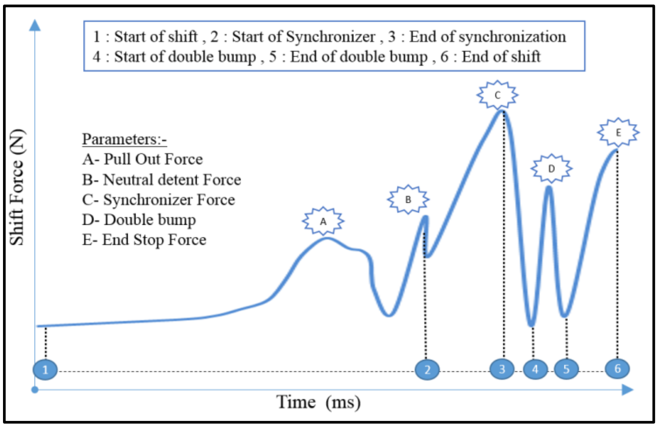


Figure 1: Synchronization phases

Synchronization process are broadly divided into five phases. Detail of each phase explained below.

Neutral Phase - No gear is selected and shifter sleeve is completely out of previous gear position. Speed gears are rotating with their own speed as per selected gears and shifter sleeve is rotating with speed of gearbox main shaft. There is speed difference between the gear and mainshaft. The detent is in neutral detent groove position.

Pre synchronization phase- Shifter sleeve starts to come out of neutral position and travel axially until strut makes contact with outer cone of synchronizer. Axial movement of strut create small amount of friction torque in the synchronizer causing angular displacement of outer cone, due to this lug on the outer cone makes contact with slot in the engaging gear this phenomenon is called as Indexing.

Synchronization Phase-Shifter sleeve starts to travel axially further and come out of spring force applied by strut and shifter sleeve teeth makes contact with outer cone teeth. The shifter sleeve teeth push the teeth of outer cone due to this friction torque starts to generate between cone surfaces of synchronizer, whichis called as cone torque.At this point shift force increased suddenly to generate friction torque that starts reducing speed difference between selected gear and targeted gear, at one stage it become zero and synchronization is completed.

Free-flight phase – Cone torque generated during synchronization stages becomes zero hence deindexing of outer cone take place due to index torque. Since synchronization is over and cone torque is zero, gearshift effort decreases rapidly this allows shifter sleeve axially travel further towards synchro ring with lesser effort.

Final engagement Phase –Shifter sleeve teeth makes contact with synchro ring teeth. Relative to dynamic position of synchro ring teeth, shifter sleeve teeth may hitit or pass through it. Secondary peak force generated after hitting of teeth on teeth know as double bump. Shifter sleeve will travel further until its makes contact with hard stop on gear this indicate completion of gear shifting. At this stage back taper of shifter sleeve engages with back taper of synchro ring ensure locking of gear.

1.2 GSQA Parameters

Gearshift quality assessment (GSQA) is experimental analysis method of measuring the parameter involve in gear shifting process. For designer GSQA helps to understand driver perception about gearshift quality into technical term.

Static GSQA Parameters
- Free play
- Cross gate travel and force
- Shift travel
- Selection spring stiffness

Dynamic GSQA Parameters
- Pull out force
- Synchronization force
- Double bump force
- Double bump to synchronization force ratio
- Time synchronization integral
- Time double bump integral

2. Methodology

The different tasks performed on this project is shown schematically in Fig-2.

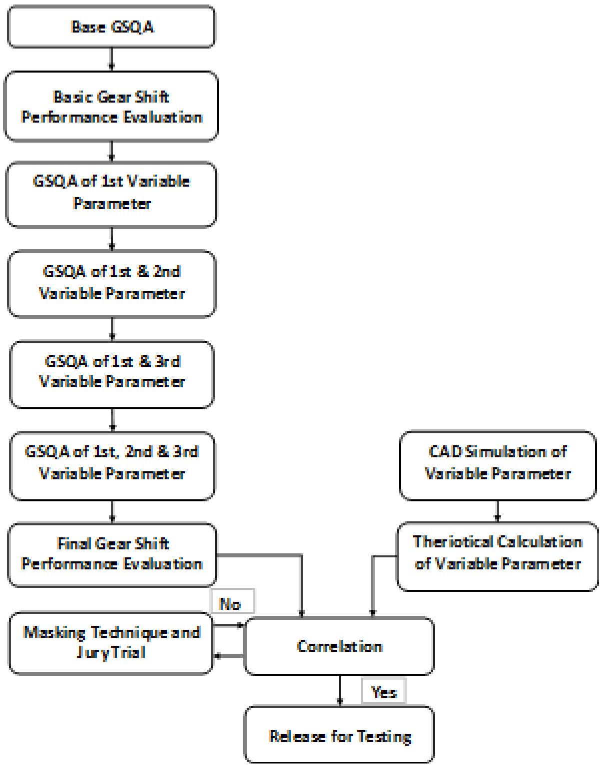


Figure 2: Methodology

3. Literature Review

RohitKunal, Ganesh Adiga, Sanjay Gill and Manish Sharma [1] have explained Simulation of Gear Shift Force Curve and Shift Rail Ramp Profile. Their paper deals with improvement of gearshift quality by optimizing the operating force path. They developed simulation tool, which can detect the significant influence of the individual parameters on the operating force curve. It also concludes on correlation between gearshift curve and physical test (GSQA analysis).

Samson R [3] describes simulation of bowden cable routing on virtual vehicle and design guidelines to achieve the best cable performance. It also describes the influence of cable routing geometry on cable transmission efficiency and procedure for simulating routing on virtual vehicle.

Manish Kumar Sharma and JineshSavla [4] discussed shift system inertia mass optimization techniques to minimize double bump for manual transmission. Their paper deals with study of various techniques to reduce the double bump and its verification for front wheel drive transaxle and rear wheel drive in-line transmission. They also claimed that reduction in dog ring chamfer angle and matching of synchronization points with ramp profile are the basic techniques for achieving the set double bump target. Additional inertia mass on shift system is alternate technique which uses stored energy in inertia mass during shifting and same force released during double bump phase to make the feel more positive.

G.B. Moir [5] describes the measurement and calculation of objective measures that relate to perceived shift quality. Conventional assessment of gearshift quality has relied on subjective rating techniques. Vehicle manufacturer uses typical scale to rate vehicle shift quality with score from 1 to 10.They do not allow the identification of the causes of poor performance, other than in general term such as shift force or double bump.

Amit Sandooja and RohitKunal [6] discussed automotive synchronizer with asymmetric toothing. In their paper, they explain synchronization process with symmetric and asymmetrical tooth arrangement. They conducted GSQA analysis to analyze effect of symmetric and asymmetrical tooth arrangement on double bump and concluded that synchronization force and double bump of asymmetric teeth is lower than symmetric teeth. They also inform difficulty to have asymmetric chamfer tooth arrangement on shift sleeve and Clutch body ring is high manufacturing and machining cost.

4. Variable Parameters

Table 1: Variable parameter selection criteria

Sr. No	List of Variable Parameters	Selection criteria					
		Time			Cost	Implementation	
		Design	Prototype	Simulation		Ease	Risk
1	Cable routing optimization	Less	Less	Less	Low	Easy	Low
2	Shifter shaft detent profile Optimization	Medium	Less	Medium	Low	Easy	Low
3	Shifter shaft detent force Optimization	Medium	Less	Medium	Low	Easy	Low
4	Counter-weight on shift linkage	Less	Medium	Medium	Moderate	Easy	Low
5	Offset chamfer on cone and ring	High	Very High	Very High	Very High	Difficult	High
6	Diagonal shifting	Medium	High	Very High	Very High	Difficult	High

After comparing variable parameters as shown in table 1,followingparameters are selected to study its effect on gearshift performance.

- Cable routing optimization
- Inertia mass on gearshift linkage
- Shifter shaft detent

4.1 Cable Routing Optimization

Gearshiftcable, which connect the gear shifter and transmission have significant effect on gearshift performance.Normal force on the cable because of Pre-loading of inner cable on outer sleeve, friction coefficients between inner cable and outer conduit and rate at which inner cable slides inside outer conduit are the key parameters that influences cable performance. This work describe methodology, which would exactly match physical routing on the vehicle with help of virtual simulation.

The main geometric parameter influencing friction between the outer housing and the inner cable is the total wrap angle of the cable system. Theoretically, the friction losses of bowden cables are similar to those occurring when sliding a cable over a stationary cylinder at constant velocity, as shown in Fig. 3.

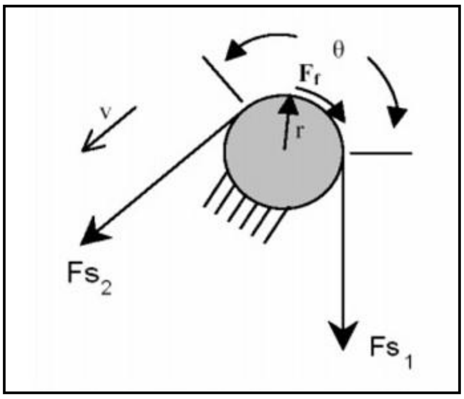


Figure 3: Force balance of cable routed around stationary cylinder [3, 7]

Force transmission can thus approximated by (1)

$$\frac{Fs_1}{Fs_2} \cong \frac{1}{e^{\mu\theta}} = e^{-\mu\theta} \quad (1)$$

Where, Fs_1 is Force at side 1 in N, Fs_2 is Force at side 2 in N, μ is Coefficient of sliding friction and θ is Summation of wrap angles of the cable around the cylinderin degrees.

Fig. 4 shows that with change in coefficient of sliding friction how cable efficiency varies exponentially with increase in wrap angle.

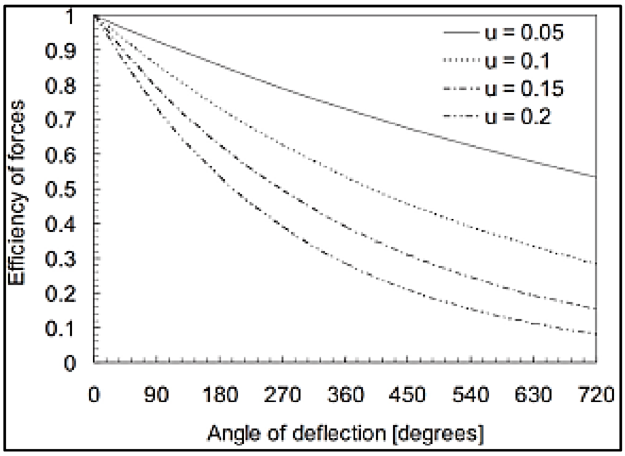


Figure 4: Theoretical force transmission efficiency in a Bowden cable system [3, 7]

LetierPierre and team [7] have explained using (1) that bending radius does not influence the cable friction but even a small deflection in bend radius increases wear of cable, which negatively influences the friction coefficient over time. Therefore, recommendation for minimum bend radius (r_m) is according to (2)

$$r_m \geq 20 \times D_{cable} \quad (2)$$

Where, $D_{cable}$is External Diameter of the cable in mm

4.2 Inertia Mass on Gear Shift Linkage

Adding inertia mass on gearshift linkage helps to store the energy during gear engagement. Stored inertia is release during final engagement phase, which significantly reduces double bump and make shift feel more noticeable. The intensity of force generated by hitting of shifter sleeve dog teeth with synchro ring dog teeth reduces due to added inertia mass.

The increase in weight gives a positive shift feel to the driver.However, addition of too much weight makes the feel sluggish and hard since the weight has to be move across the shift stroke. This problem can resolved with by increasing shift lever ratio. However,it will lead to increase in shift travel. There is risk of gear jump-out due to gearshift linkage increased inertia mass.In designing of single inertia mass care has been taken to match C.G of inertia mass with centre line of top cover. Inertia mass as shown in Fig.5, whichis directly mounted on gearbox shift linkage as shown in fig. 6.

$$Fa = \left\{\frac{\mathrm{I\ x\ \Delta n\ x\ tan}\ \alpha}{\mathrm{Rx\ T3}} + \frac{\mathrm{M\ x\ Vo}}{\mathrm{T3}}\right\} x\ \frac{\eta}{\mathrm{Lr}} \quad (3)$$

Where, Fa is Impact force in N, I is Synchronized inertia in Kgm2, Δn is Speed difference between shifter sleeve and gear engagement ring, α is Sleeve teeth chamfer angles in degrees, R is Pitch circle diameter of shifter sleeve in m, T3 is Time in second, M is Mass in kg, Vo is Shift speed in m/s, ɳ is Shift system efficiency and Lr is Leverage ratio or linkage ratio.

As per (3) when the shift mass increases the impact force on sleeve increases. Since the impact force is coming from the inertia mass, the driver does not perceive the double bump on gear knob.

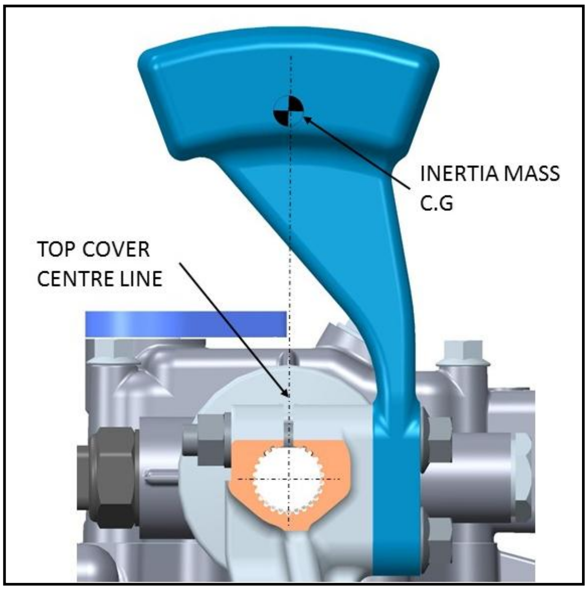


Figure 5: Inertia mass C.G

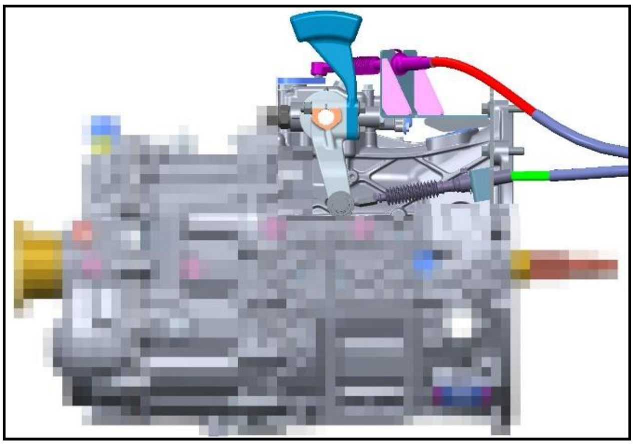


Figure 6: Gearbox with inertia mass

4.3 Shifter Shaft Detent

Shifter shaft detent profile is optimized by understanding dynamic behavior of synchronizer during gear engagement and disengagement condition. Detent profile path is correlated to the synchronizer travel to get benefit of negative force generated after completion of synchronization process. To get maximum benefit from detent force, detent need to actuate in free flight zone. New detent is design to improve rate of drop of detent force to match synchronization travel. The negative force (suction feeling)increasesafter synchronization and helps in reducing in double bump. Shifter shaft detent also helps in resolving gear jump-out issue caused by added gearshift linkage inertia. Shaft detent act as positive lock when gear is in engaged condition. While disengaging gear more force is required to overcome detent spring force, whichreduces gear jump-out but increases pull out force. Fig. 7 shows variation in detent force with respect to shifter shaft travel. Fig. 8 shows forces acting on detent ball due to shaft profile.

Rohitkunaland coworkers [1] have explainedusing (4,5)that rate of drop of the detent force is more dependent on the slope rather than on detent preload except a few variation. For friction between shaft ramp profile and detent ball is assumed as 0 so **tan (δ) = 0**

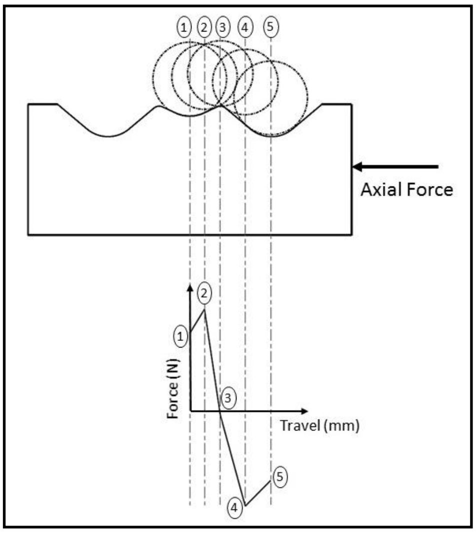


Figure 7: Shifter shaft detent forceVs travel

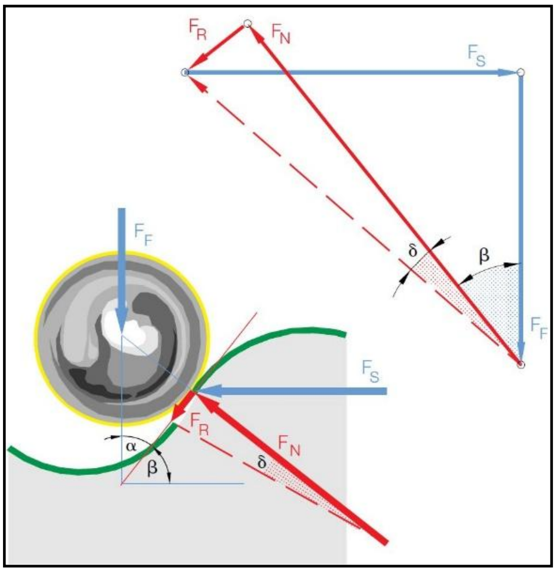


Figure 8: Force acting on detent ball and resulting pattern of forces [2]

$$F_S = F_F x \tan(\beta + \delta) \quad (4)$$
$$\mu = \tan\delta \quad (5)$$

Where,F_S is Gearshift force in N, F_F is Spring preload force in N, δ is friction angle in degrees, β,α is Ramp angle in degrees. ($\beta = 90^0 - \alpha$) and μ is Coefficient of friction.

5. Double Bump Masking

We can predict dynamic behavior of synchronizer to certain level, but double bump is inevitable characteristic of synchronizer.Direct shift linkage system and remote shift linkage system have severe double bump perception as slight change in force or vibration inside the gearbox get transfer to the driver with help of linkage.Cable shift linkage have comparatively less severe double bump perception as gearbox and knob are connected to flexible cable. To reduce double bump perception at gearshift knob below mention-masking techniques are used.

- Rubber damper on cable end fitting
- Rubber damper on gear shifter mounting.
- Gear shift knob grip

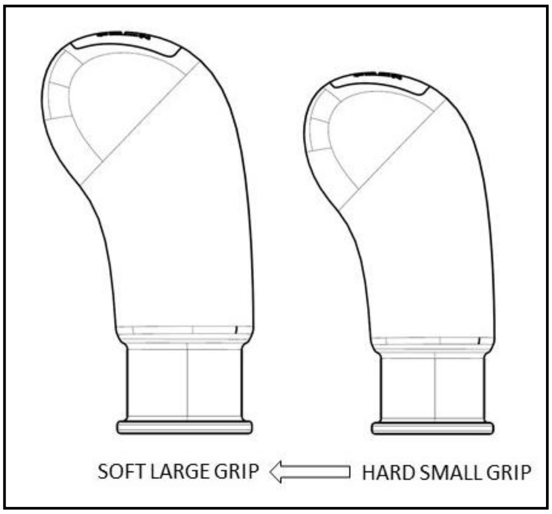


Figure 9: Gearshift knob with change in grip

In designing care has been taken for rubber thickness and shore hardness selection, as addition of too much rubber will deteriorate shift feel. Fig.9 shows gearshift knob with change in grip. Fig. 10 shows gear shifter mounting arrangement on dashboard with help of rubber damper.

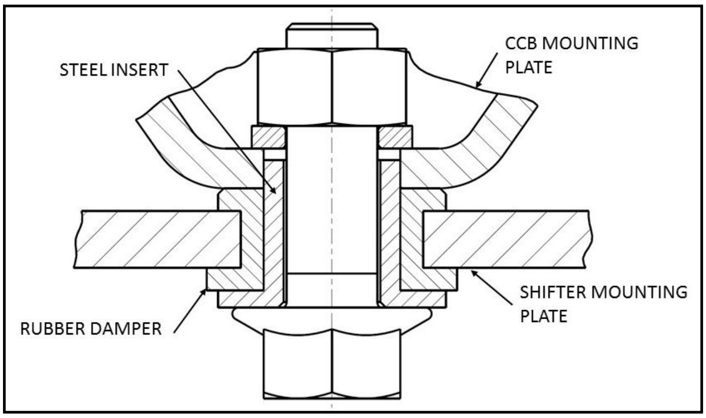
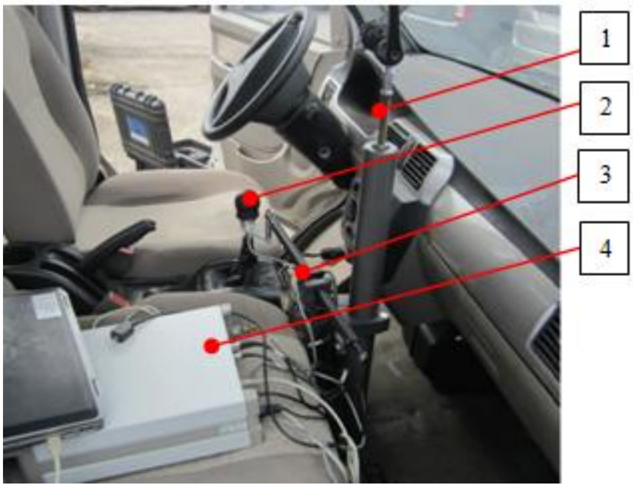


Figure 10: Gear shifter mounting arrangement on vehicle dashboard**.**

6. Test Setup

As shown in Fig. 11 Ricardo's Gear Shift Quality Assessment (GSQA) was use to collect experimental data and to study gearshift performance of manual transmission. In order to acquire experimental data, a holding stand was setup with bottom side fitting on the floor and top side fitting on windshield glass with help of vacuum cup arrangement. The force sensor integrated with shift knobwas mounted on gearshift lever. Angle and displacement sensor was mounted on holding stand and one end is connected to the shift knob [8]. Data acquisition unit is used to record dynamic behavior of transmission. The precision of force recorded by instrument was 0.01N; the precision of displacement recorded by instrument was 0.01 mm.



(1) Holding Stand (3) Angle and Displacement Sensor
(2) Force Sensor (4) Data Acquisition Unit

Figure 11: GSQA instrument setup [8]

7. Result and Discussion

Ricardo GSQA instrument set was use to collect transmission gearshift performance data from vehicle. Initially base

GSQA data was collected and then one by one gearbox was upgraded with variable parameter and again GSQA data collected. Evaluation of gearshift performance was carried out to understand effect of each variable parameter. Below listed test were performed to collect experimental data.

Test 1 (Base data) –
Initial GSQA data was collected to understand scope of improvement, which is taken as base data.

Test 2 (Cable routing) –
Cable routing optimization marginallyhelped in gearshift performance improvement, although it helped to reduce cable length. The reduction has been achieved by rerouting the cable through shortest route without affecting function.

Test 3 (Cable routing + Inertia mass) –
The combination of cable routing and Inertia mass has shown significant gearshift performance improvement specially in double bump area. However gear jump-out is observed during trials due increase in inertia mass.

Test 4 (Cable routing+ Detent) –
The combination of cable routing andshaft detent marginally improved gearshift performance. In this case negative force generated is much lower and hence it influence on is low. Shaft detent helped in elimination of gear jump-out but rise in pull out force was observed.

Test 5 (Cable routing + Inertia mass + Detent) –
Parameter such as cable routing optimization, gearshift linkage inertia mass and shaft detent combine together significantly helped to improve the gearshift performance.Itis observed that double bump to synchro ratio is lower than target. Acceptable increment in pull out force and detent force was observed due to inertia mass and detent spring force.

The above conducted trails do not satisfies the objective. Some trails were conducted by modifying the fitments on gearshift knob and shifter mounting arrangement and subjected to jury trails. GSQA trails could not be conducted with this modification.

Jury trial –
It is subjective rating technique in which gearshift performance is rated on scale of 1 to 10 (bad to good) [5,9].The overall gearshift performance is reviewed against 13 subjective parameters. In jury trial overall gearshift performance is rated to scale of 8 which means gearshift performance surpassed acceptable criteria.

Fig. 12 and Fig. 13 shows the variation of force Vs time against test 1 and test 5 for 1st - 2nd for upshifting and 2nd - 1st for downshifting respectively. Fig. 14 shows subjective evaluation results of jury trail.

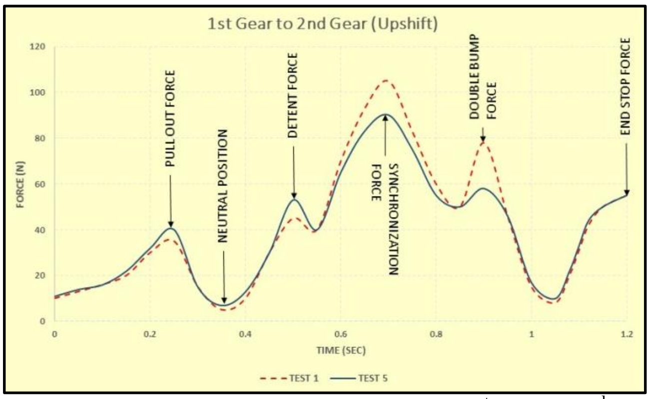


Figure 12: Test 1 Vs Test 5 result for 1stgear to 2ndgear during upshifting.

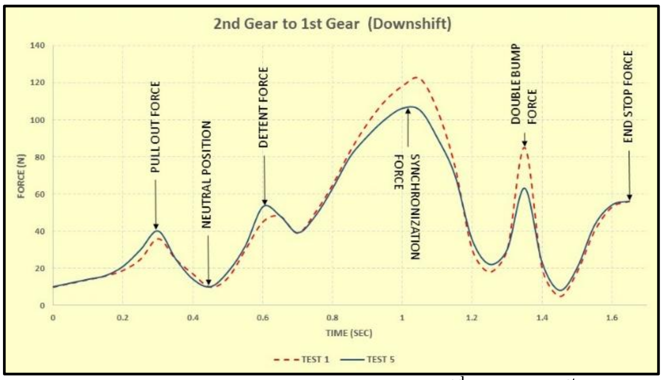


Figure 13: Test 1 Vs Test 5 result for 2nd gear to 1st gear during downshifting.

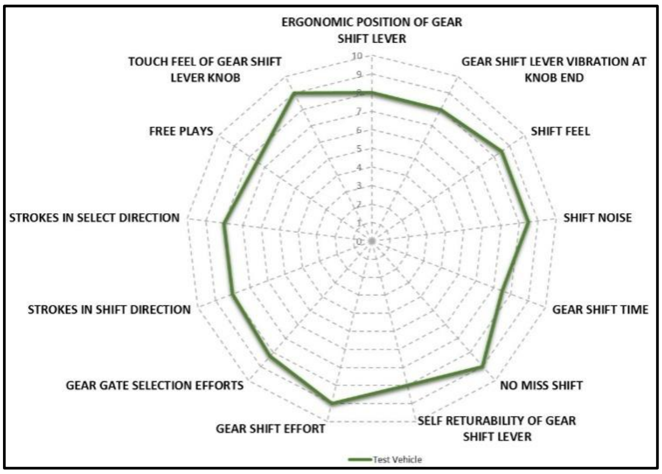


Figure 14: Test result of subjective evaluation by Jury Trial

8. Conclusion

During project work,5dynamic tests and 1 subjective evaluation test were performed and result of each dynamic test was compared with each other. This outcome of this work can be summarized as,

- Only dynamic tests were conducted and not static.
- Out of 5 dynamic tests 3 tests were conducted in combination.
- Test 1 raised a red flagas few of gearshift parameters are not meeting GSQA targets.
- Some improvement in gearshift performance were observed in Test 2. Cable routing optimization helped to reduce cable length, whichin turn helped to reduce friction.

Force transmission efficiency improved by maintaining minimum bend radius and cable rerouting.

- In test 3 considerableimprovement in gearshift performancewere achieved with help of gearshift linkage inertia mass. Due to inertia mass impact force was generated which in turn helped to reduce double bump. Increased in inertia mass alsoincreases gear jump-out.
- Some improvement in gearshift performance were observed in test 4. Negative force generated after synchronization helped in reduction of double bump force. Shifter shaft detent profile helped in elimination of gear jump-out problem.
- Test 5 was performed with combination of variable parameters like cable routing optimization, Inertia mass on gearshift linkage and shifter shaft detent. Significant improvement in gearshift performance was observed over test 1, but double bump to synchro ratio target was marginally fall behind.
- After test 5vehicle was updated with rubber damper and offered to jury for trial. Change in knob grip and shifter mounting with rubber damper help to camouflage double bump effect. Due to this driver is not able to perceive double bump force at knob. In jury trial vehicle has exceeded acceptable criteria for gearshift performance.

9. Scope for Future Work

In present work, 3 variable parameters are selected considering time, cost and implementation risk factor. However, other parameters should be studied in details such as synchro ring, shifter sleeve asymmetric toothing [6] and diagonal shift [10] for further gearshift performance enhancement.

10. Acknowledgments

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