Gear Shift Efforts Analysis and User Interface Software Development

Emrah Arslan*‡, Ahmet Sagirli**

* Yildiz Technical University, Department of Mechanical Engineering, Besiktas 34220, Istanbul,Turkey, Ford Otomotiv Sanayi A.S. Sancaktepe Engineering, 34885 Sancaktepe, Istanbul,Turkey

** Yildiz Technical University, Department of Mechanical Engineering, Besiktas 34220, Istanbul,Turkey

(earslan9@ford.com, sagirli@yildiz.edu.tr)

‡ Corresponding Author; Emrah Arslan, Department of Mechanical Engineering, Faculty of Machine,Yildiz Technical University,34220,Istanbul, Turkey, Tel: +90 216 664 9451,earslan9@ford.com

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Abstract- Nowadays, with the increasing demand of comfort on passenger cars, many car manufacturer companies focus on manual transmission and external control system. There are many gearshift control mechanisms available such as rod mechanism, hydraulics mechanism and cable mechanism in the current technics that need to be designed resplendently. In the meantime, base manual transmission has a lot of components such as synchronizer, gear cones, friction plates, poppet balls, hubs and rods which affect gear shift comfort. All these main components should be designed and optimized for customer satisfaction. In order to measure gear shift efforts and comfort, Gear Shift Quality Analysis (GSQA) device is developed by Ricardo Company. Using this GSQA device, gear shift force, gear shift integral, free plays, cross gate positions, fore-aft positions, shifter angles are able to be measured objectively. To collect all these attributes data, engineers should spend minimum one day on a selected vehicle. This means loss of work and money for the car manufacturers. The gear shift effort software (GSEA) for a manual transmission and external control mechanism are developed to evaluate/calculate shift and select mechanical ratio, cable strokes, length lever and shift force to provide desirable shifting quality. In addition to software calculation, the vehicle is tested using gear shift quality device. At the end of this study input parameters are discussed in terms of outputs of vehicle shift quality attributes. The results of simulation software are plotted to present easy understanding for the last user.

Keywords Synchronizer, shift quality, shift effort, external control.

1. Introduction

Vehicle manual transmission systems are main parts of the automotive powertrain pack. To reach the aim to achieve gear shift, synchronizers should move through the target gears. External control components allow fore-aft and cross gate movement to the driver thanks to the fact that shifter knob is one of the main components that interface with customers. Its key properties are to change the work of gear at certain vehicle speeds. Many car manufacturer companies use cable shift system for their manual transmission system because of smooth installation, transformable routing and flexibility.

The efforts of gear shift force can be typified by using different calculation methods. There are three main systems to understand the whole shifting process:

External Control System

- Handball Mechanism (Shifter)
- Shifter Cables
- Shift Turret Mass

Internal Control System

- Selector Springs and Poppet Balls
- Push Rods and Levers
- Gear Shift Sleeve Forks

Synchronizer System

- Clutch gear with cone
- Gear Wheel
- Synchronizer Ring
- Synchronizer Rotational Hub
- Sliding Sleeve
- Strut Detent
- Output Shaft

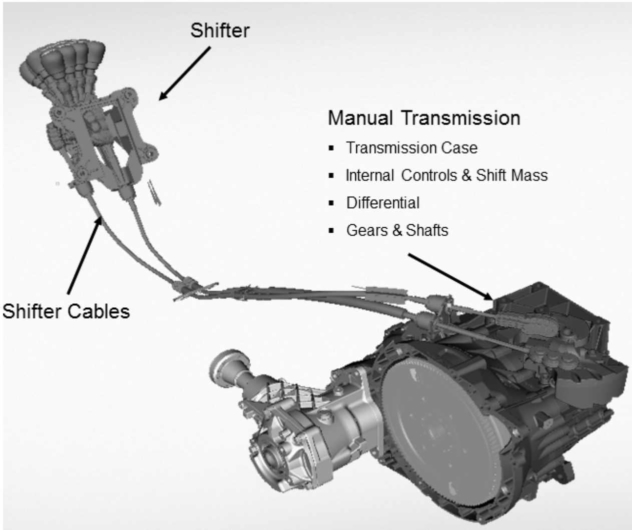

Fig. 1. Complete manual transmission system.

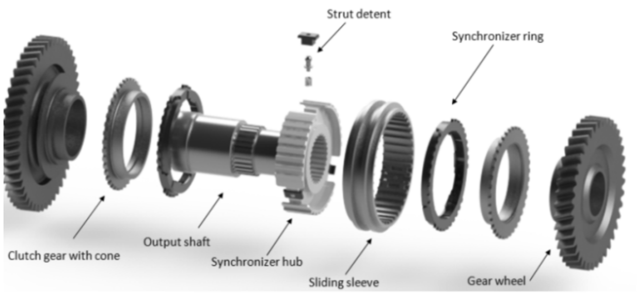

Fig. 2. Synchronizer detail view [4].

The gear shift comfort for a manual transmission is directly connected to operator's feeling of the gear force transferred. Reduced shifting force and increased uniformity should be considered for developing manual transmission [2]. Within this scope, driver effects on gear shift force are broken down using different trained operator. Thus, the results were correlated and transferred to theoretical function [3].

The Synchronizer sleeve is manually triggered using fork and internal shift control system connected to the external control in the vehicle system. Although synchronizer system is the most critical component for shift quality, there are other systems that stimulate customer complaints. In order to simulate other attributes effects such as gear knob, forks, levers and poppet ball, a dynamic shift quality model was created using Matlab Simulink Software [5].

As it is a mere function of synchronizer a manual transmission's dynamic gearshift quality is a very vital parameter. The behavior of dynamic gearshift parameter during gearshift is eminently nonlinear and random, therefore it is challenging to obtain acceptable gearshift. The most complex circumstance in manual transmission is to design the synchronizer and its dynamic behavior. The prediction of the behavior of most dynamic and static parameters such as pull out force, synchronization force, detent force and end stop force is managed via calculation and they are dependent on the design of the synchronizer and gearbox layout [10].

Ana Pastor Bedmar [4] simplified linear synchronizer model and presented that if synchronizer parameters are selected correspondingly, that may help reduce the gearbox shift effort. Synchro parameters are very key elements to reduce handball effort issue.

In order to establish optimum cone parameter, a mathematical optimization model can be developed. Between the cone angle and sleeve champers angle, synchronizer size, coefficient of friction, cone torque and index torque, a model of relationship can be set up. To find a global minimum value of cone angle to satisfy a pack of assigned and known constraints, a model was framed in the Matlab optimization toolbox pattern-search solver. The mentioned model can be applied for selecting the first cut synchro parameter within moderate accuracy. These values can be finer tuned afterwards with the help of customized and specialized software systems [6].

In this paper, a mathematical calculation was utilized based on perfect conditions by using parameters of compression shift and select mechanical ratio, cone angle, friction coefficient, shifting time in order to understand the driver's felling of a manual transmission. Theoretical calculations in this study are compared to real vehicle measurements. Simulation results are presented with guide interface to the engineers. Gear Shift Calculation Tool is developed using Microsoft .NET Framework 4.5 backend platform.

2. Mathematical model of gear shift calculation

A detailed knowledge of the process of gear-change is required to study the synchronizer behavior. Successive phases are able to be distinguishable with the help of both different relative positions of the synchronizer parts and the characteristic points of synchronized angular velocity and the axial force variation [8].

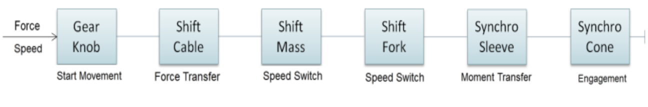

Fig. 3. Shift control system force and velocity transfer.

Figure 3 shows handball forces and velocity transformation between key elements. All these sub components create concurrent execution together. The gear knob transfers force transmission via shifter cable and shift mass. In this system, there are two speed cycles between components.

- Shift mass converts linear movement to angular movement
- Shift fork converts angular movement to linear movement.

Synchro sleeve pushes the gear cones to target gear with the movement of the fork.

There are 4 main sections of gear shifting process. The following Fig. 5 shows the generic simulation process that affects the driver hand lever ball.

Neutral: Neutral position is the center of gear knob, fore-aft and gross gate movements start from this position.

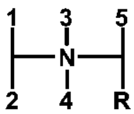

Fig. 4. 5 Speed gear hand ball pattern.

Start of Synchronization: The gear shift sleeve moves to fore-aft direction from the N position. Driver passes this phase without remarkable force effect, only with internal frictions.

Synchronization: At this phase synchronization hub moves axial to target gear and gear cones work in parallel with synchro sleeve. The cones complete physical connection.

Blocking Release: The dog teeth fully engage into each other and synchronizer sleeve completes shape connection.

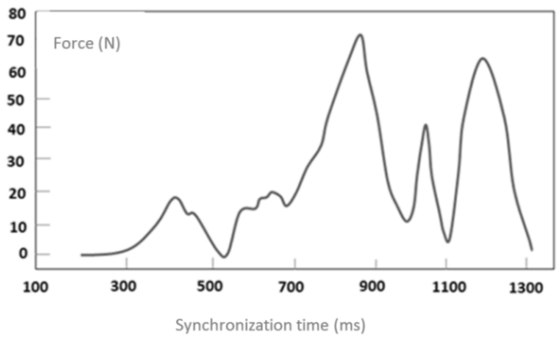

Fig. 5. Synchronization handball force-time chart.

The synchronization integral (Is) can be defined as hand ball gear shift force that depends on the time period of shifting.

$$I_S = \int_{t_0}^{t_1} F_{handball}(t).dt \tag{1}$$

Where I_S is the synchronization integral force, t_0 is the time of synchronization start, t_1 is the time of synchronization finish, $F_{handball}$ is the force which applied on shifter gear knob. If we consider non-variable values in $F_{handball}$, we can convert it to Eq. (2).

$$F_{handball} = \frac{K.F_{cone}}{\gamma_h.\gamma_m.\gamma_i} \tag{2}$$

Where K is the shift mechanical ratio which is proportional with shifter lengths, γ_h is gear shift/select cable efficiency which is provided by cable suppliers, γ_m is shifter efficiency, γ_i is internal control system efficiency, F_{cone} is cone force at the mean point.

$$I_S = \int_{t_0}^{t_1} \frac{K.F_{cone}}{\gamma_h.\gamma_m.\gamma_i}.dt \tag{3}$$

The following equations are derived from Eq. (3).

$$I_S = \frac{K}{\gamma_h.\gamma_m.\gamma_i}.\int_{t_0}^{t_1} F_{cone}.dt \tag{4}$$

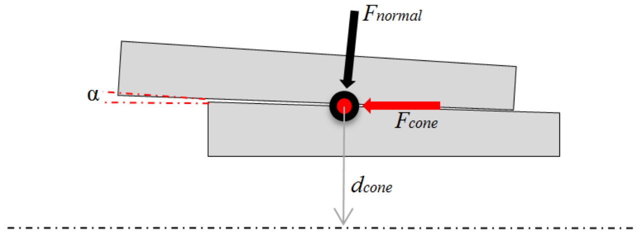

Fig. 6. Forces on gear cones.

Applied friction force on synchronizer sleeve at cone diameter creates cone torque. The equation of forces in the following form .

$$F_{cone} = F_{normal}.\sin\alpha \tag{5}$$

$$T_{friction} = F_{normal}.r_m.\mu.n_k \tag{6}$$

$$r_m = d_{cone}/2 \tag{7}$$

$$T_{friction} = \frac{F_{cone}.d_{cone}.\mu.n_k}{2.\sin\alpha} \tag{8}$$

This friction torque corresponds to the angular speed of the synchronizer.

$$T_{friction} = J.\frac{\Delta\omega}{t} \tag{9}$$

$$F_{cone} = \frac{J.\Delta\omega.2.\sin\alpha}{d_{cone}.\mu.n_k.t} \tag{10}$$

Where J is total inertia of the system which can be divided as drag and rotational inertia, $\Delta\omega$ is speed difference of the target gear and current gear, α is cone angle of synchronizer, d_{cone} is cone diameter, r_m is cone radius, μ is friction coefficient of cone, n is friction coefficient of cone, n_k is the number of cone and t is the synchronization period of gear shift process. The handball force is the driver's feeling of force which is defined as following

$$F_{handball} = \frac{K}{\gamma_h.\gamma_m.\gamma_i}.\frac{J.\Delta\omega.2.\sin\alpha}{d_{cone}.\mu.n_k.t} \tag{11}$$

Manual transmission synchronizers use friction cones to equalize current gear and target gear speed. Working principle of manual transmission cones is similar to the dry clutch mechanism [9]. In Table 1, synchronizer cone angles are given corresponding to cone number.

Table 1. Cone numbers and angles [9]

Single Cone	Multi Cone
n=1 *α=6.5-8°*	*n>1* *α=7-12°*

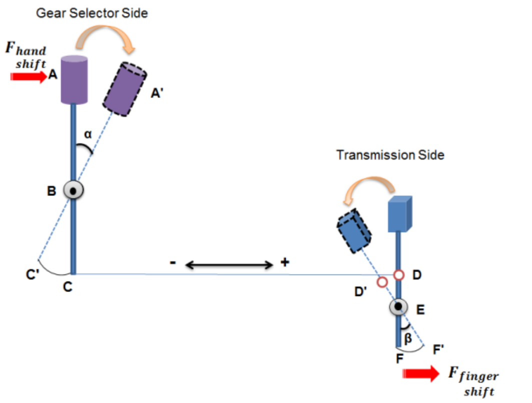

Fig. 7. Shift movement mechanical dimensions.

According to Fig.7 shift mechanical ratio is as follows,

$$K\ (\text{Shift Mechanical Ratio}) = \frac{|AB|}{|BC|}\ X\ \frac{|DE|}{|EF|} \tag{11}$$

Where |AB| is hand lever length of shift knob, |BC| is shift radius on shifter, |DE| is shift radius on transmission and |EF| is finger radius on transmission shift shaft. To protect synchronizers, shift mechanical ratio is limited by the car manufacturer companies. According to research and experimental results, mechanical ratio proposals are defined as follows

- Heavy Commercial Transmissions ($\leq 7{,}5$)
- Passenger Car Transmissions (≤ 6)

Here, the force on shift forks can be defined below,

$$F_{hand\ shift} = \frac{F_{fingershift}}{K} \tag{12}$$

Where $F_{fingershift}$ is a force that is activated by shifter and lever mass.

3. Guide interface development studies

Gear shift effort analyzer (GSEA) software is developed using Devexpress Winforms tool. As programing language, .Net platform was selected.

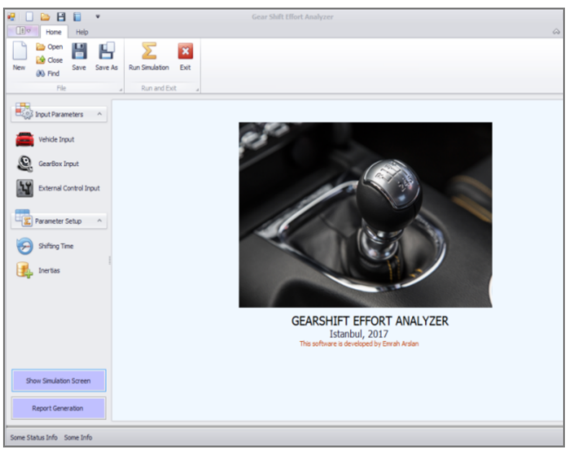

Fig. 8. Opening page of the GSEA.

To classify calculation, vehicle input parameter page is created, the user can select project id, vehicle segment, model year, engine type and transmission information in this section. When the user selects transmission and drive configuration, software brings external control inputs, synchronizer inputs and inertia values from the database. The database is created using Microsoft Access 2012. After all inputs selected, we need to save these configurations.

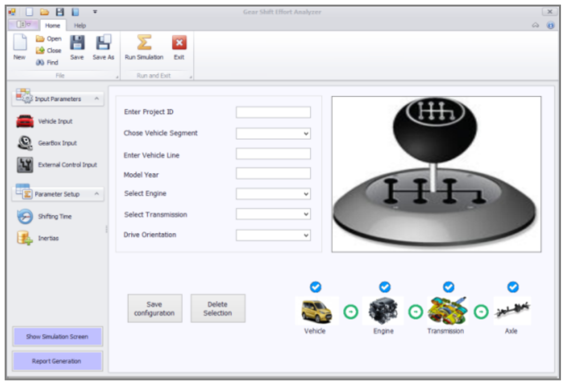

Fig. 9. New project page.

External control parameters can be determined and selected in Fig.10. There are two main sections as select and shift calculation in this page. In addition to main calculation like mechanical ratio and travels, cable adjustment comparison is added in the select tab. Shift cable and select cable efficiencies were also added in tool and the user can arrange these values easily.

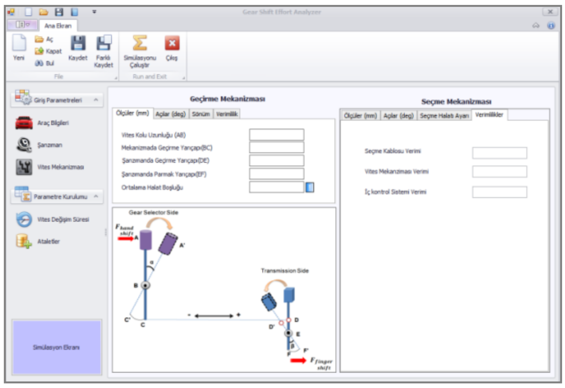

Fig. 10. External control input page.

Figure 11 shows synchronizer input parameters screen, the user needs to enter cone angle (degree), cone number, cone friction and mean cone radius in this tab.

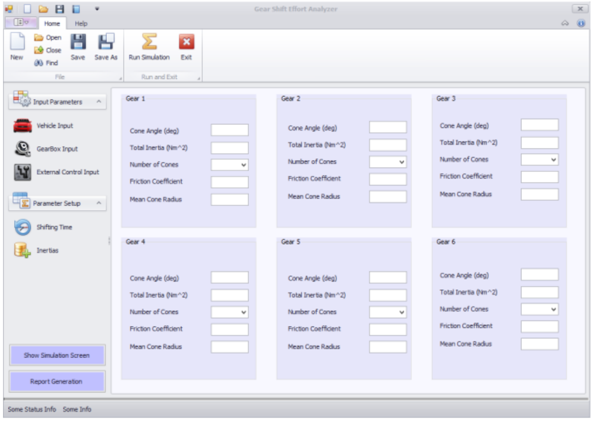

Fig. 11. Synchronizers input page.

In parameter setup section, the user sets clutch inertia, drag inertia and speed difference in both upshift and downshift gear change. The speed differences between gears come from the gear ratios. Gear shift speed was selected as nominal 3000 rpm.

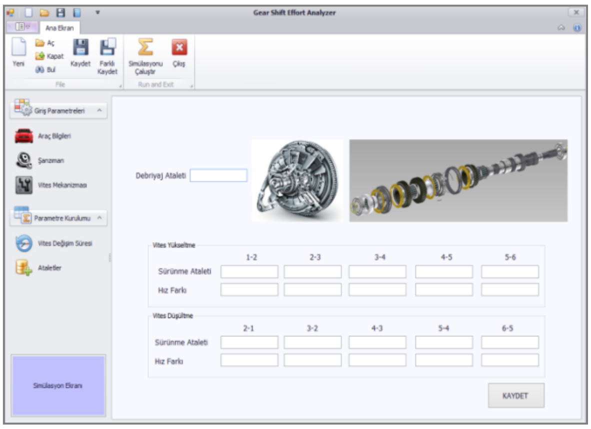

Fig. 12. Inertia and speed input page.

After above parameters set-up, the user needs to run simulation. During simulation process, solver prepares charts and summary pages. There are three tabs in the result page as external control summary, external control chart and shift force tabs.

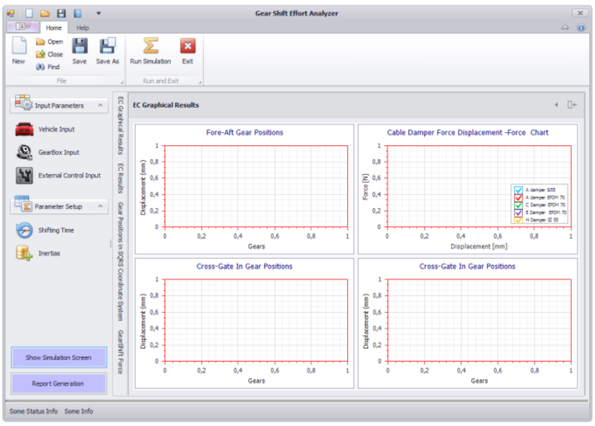

Fig. 13. Results Page.

Using GSEA software, we can evaluate and calculate as follows,

- Upshift Force (N)
- Downshift Force (N)
- Fore-Aft Positions (mm)
- Cross-Gate Positions (mm)
- Shifter Mechanical Ratio
- Gear Positions in Coordinate System (mm)

4. Gear shift quality device (GSQA) and test setup

Transmission gear shift quality can be evaluated using Ricardo's GSQA device. The advantages of the device to show us objective results, also this device can be used in back to back comparison between vehicle lines and transmissions.

Fig. 14. Ricardo GSQA device.

The GSQA measures shift and select travels, free plays, shift and select forces on the system using many sensor setups and acquisition devices. The acquisition device collects all measured data and analyses, after processing the data, test driver is shown the results on the main screen. For the setup process, light commercial vehicle 6 speed transmission was selected.

Table 2. Gear Ratios

1st	2nd	3rd	4th	5th	6th
3,62	2,05	1,19	0,810	0,902	0,71

Table 3. Synchronizers Parameters

Gears	Cone Angele	Cone Numbers	Cone Friction	Cone Radius
1st	7,3°	3	0,1	73
2nd	7,3°	3	0,1	73
3rd	7,1°	3	0,1	65
4th	7,1°	3	0,1	65
5th	6,8°	2	0,1	68
6th	6,8°	2	0,1	68

In this study, dry clutch disk inertia is selected as 0, 0091 kgm^2.

5. Simulation and Experimental Test Results

Figure 15 shows simulation results for cross-gate positions. Travel response of the forks and levers are plotted. There are two motion cables for manual transmission system which are shift and select cable. The select cable works for gross-gate positions such as 1-2, 5-6 and reverse lines. At the same time manual transmission system has adjustment system on the select cable. The adjustment part assures handball positions for 1-2 and 5-6 lines.

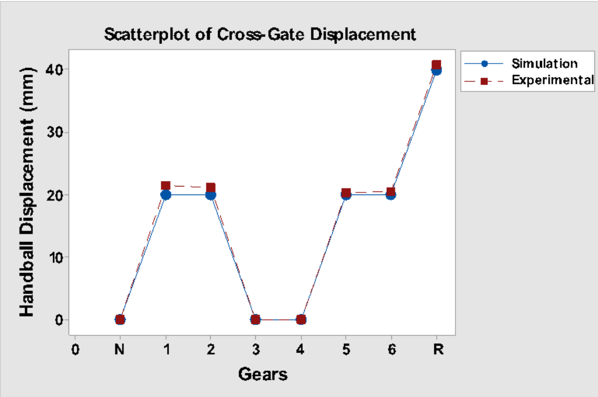

Fig. 15. Simulation & experimental cross-gate positions.

Car manufacturer companies check select cable adjustment for each car with a camera system. The camera measures gear knob positions and informs the operator whether is it a pass or fail. This is because it is important to know select cable adjustment effects on shift quality before production phase. Another point to evaluate is the symmetry of the gear knob lever in the vehicle console. If the symmetry of the knob is not achieved, we can say that cable adjustment is not correct.

Figure 16 shows simulation and experimental results for fore-aft positions. Travel response of the sleeve is plotted. The simulation results give 50 mm for fore-aft simulation and this is the same for all gears due to the same shifter angle.

Due to end stop stiffness of the shifter cable, we see a minor wave on fore-aft positions for the experimental test results. Shifter cable that has low end stop stiffness creates high free play on gear lever knob. Transmission transmits powertrain vibrations to gear knob via shifter cable, for this reason stiffness value should be within the defined range.

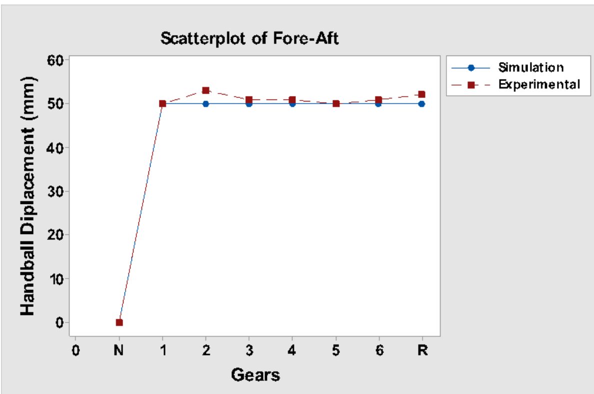

Fig. 16. Simulation & experimental fore-aft positions.

The most important attribute of shift quality is hand ball efforts. We can divide efforts into two sections as downshift and upshift. In Fig. 18, experimental and simulation results for upshift forces are shown. In here, number of cones plays a major role in shiftability. Using more than one synchro cone marks up the transmission price.

Fig. 17. Ricardo GSQA device [7].

Figure 17 shows GSQA test system in vehicle compartment. Expert driver collects shift quality data to give sign off to customer vehicles.

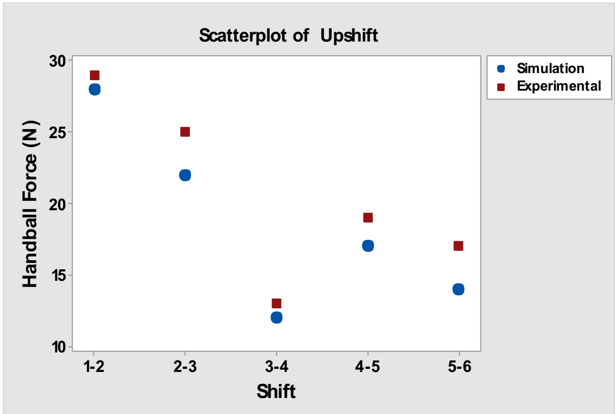

Fig.18. Simulation & experimental upshift force.

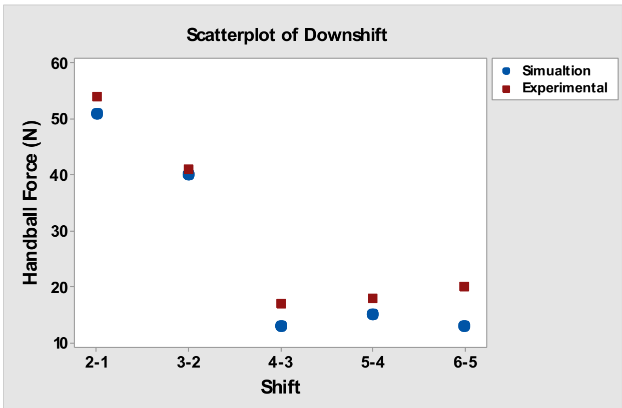

Fig.19. Simulation & experimental dowbshift force.

Figure 19 explains that lower shifts especially the 1st and 2nd gears have high efforts. The reason is that these gears have bigger cones and gear change inertias. The drag inertia can be measured in transmission rig test. Oil viscosity is an important factor for drag inertia. Using oil that has high viscosity increases shift force. Transmission suppliers share catalogue inertia values with OEM's. In addition to inertia and cone size, there is another important factor which is cone number. Especially lower gear changes like 1st to 2nd and 2nd to 1st need high energy to engage gears to each other. In such case, transmission manufacturers use more than one friction cone to reduce sleeve force. We have tested two and three cones system for the selected case. For passenger cars, all transmission manufactures use one cone systems for high shifts such as 4/5 and 5/6 due to lower torque indexing.

The shift quality can be affected by components with elastic properties within the system. In general, these components are poppet ball springs, cable end eyes and abutments. With arranging the parameters in themselves, we can change shift efforts accordingly. As a sequence of this, companies focus on optimization methods to constitute the best system for their customers.

Above Fig. 18 and 19 show us experimental and simulation results converge approximately %85 which is an acceptable value if we consider test prices and time loss.

Table 4. Comparison of upshift efforts [N]

Gear Shift ➔	1/2	2/3	3/4	4/5	5/6
GSQA	28	22	12	17	14
GSEA	31	24	15	19	17

Table 5. Comparison of downshift efforts [N]

Gear Shift ➔	2/1	3/2	4/3	5/4	6/5
GSQA	49	41	13	14	12
GSEA	53	46	16	16	20

6. Conclusion

This paper has shown how a guide user interface modelling software has been used for a comparison between gear shift quality device test systems. The synchronizer sleeve and cones are patterned as four stages close to real time conditions. The GSEA tool calculates the gear knob travels, positions, shift force and select force. Modelling offers transparent pictures of design parameters such as cone number, frictions, cone radius and drag inertias that has effect on dynamic shiftability. The simulation results correlate with the GSQA data collected from the target vehicle. Thus, the developed GSEA software can be used for new model vehicle transmission systems development in terms of gear shift quality.

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