

Shifter Fork Stiffness Correlation to Gear Shift Quality

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ABSTRACT

Shift quality of a manual transmission is a critical characteristic that requires utmost care while structuring the transmission. Shift quality is affected by many factors viz. synchronizer design, shifter design, gear design, transmission oil selection etc. This paper presents a correlation between stiffness of the shift fork in manual transmission with the gear shift quality using a gear shift quality assessment setup. Stiffness of shifter fork is optimized using contact pattern analysis and stiffness analysis on MSC Nastran. All the subsystem (i.e. synchronizer and the shift system component) are constrained to optimize the shift fork stiffness. A-5-speed manual transmission is used as an example to illustrate the same. A direct correlation of gear shift fork stiffness with the shift force experienced by the driver is established. The shift system was modeled in the UG NX 6.0 software to collate the synchronization force, shift system gap etc with the constraint on the shift fork. The shift fork is constrained by the synchronizer sleeve and the fork mounting on the gear shift rail. The synchronizer force is then applied on the gear shift fork pads which are translated to the synchronizer sleeve. It has a number of pads which come into contact at different occasion of the synchronization because of the varying stiffness of the fork. The contact is distributed to optimize the deflection of the fork in the synchronizer for abuse load.

The synchronization force is distributed over the pads which are in contact during the synchronization phase. The fork tends to deflect with the synchronizer sleeve during synchronization thus acting as a damper and storing energy. In the free flight zone the energy is released to provide a positive drop (The derivative function of the detent ramp profile should turn negative) and reducing the double bump i.e. (the force generated when the synchronizer sleeve hits the clutch body ring) during synchronization. It also reduces the fork preloading as the fork is retrieved after synchronization from the sleeve contact. The gear shift lever vibration and gear rattle is also reduces as the shift fork contact from the gear shift sleeve is relieved.

The optimized stiffness was tested in a vehicle and force impact was closely measured using GSQA. Using this approach the impact of stiffness was directly studied and results were verified.

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INTRODUCTION

The improvement of gearshift quality in a manual transmission has become more prevalent over the past few years as the refinement of other 'vehicle to driver' interfaces has improved. Ricardo has many years of experience in investigating gearshift quality problems and has created software and hardware for the measurement and analysis of

gearshift quality. This system, the Gear Shift Quality Assessment system (GSQA), is sold commercially and currently has 24 users world-wide ranging from vehicle manufacturers to transmission suppliers. Gearshift quality is made up of several different areas, including gate definition, shift effort, second load, double bump, fork stiffness and vehicle response. Gate definition requires careful design of both the internal and external selector mechanism, paying

attention to the compliance, static load, backlash, friction, cross gate loads and gear positions. Shift effort requires careful sizing of the synchronizer cones, cone angle, friction material and balancing this with the transmission system's reflected moment of inertia, clutch inertia and transmission drag. Gate definition is a static or quasi-static function and can be defined by careful design and selection of relevant parameters. Shift effort is a quasi-static function, which can be defined by consideration of quasi static equations. Second load however is a dynamic event and depends on the response of the entire system, including the selector mechanism, transmission, driveline, and synchronizer system. To complement the GSQA system many firms have developed a series of dynamic models to investigate the dynamic effects of gearshift quality at the design stage and for specific gearshift quality development. These models are normally generated in MATLAB Simulink although a model has also been generated in ADAMS. 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.

GSQA SETUP



Figure 1. GSQA Setup in Vehicle.

The Gear Shift Quality Assessment (GSQA) system is a complete hardware and software test solution which allows objective analysis of gearshift quality in manual transmissions. GSQA can be implemented in-vehicle or on test rig.

Gearshift quality has traditionally been determined by subjective assessment conducted by test drivers; unfortunately this suffers from inevitable variations due to different driving styles and individual driver interpretation of a given gearshift. Since 1993 Ricardo has continually developed techniques to characterize synchronized shift quality using objective measures, rather than relying on traditional subjective rating techniques.

Ricardo have a complete suite of gear shift quality hardware and software tools from basic synchronizer design software through to complete shift system and driveline modeling, and gear shift durability test rig software. The GSQA system is part of this suite of tools. An additional

GSQA module is available for trucks with increased force, travel and range/split gear selections.

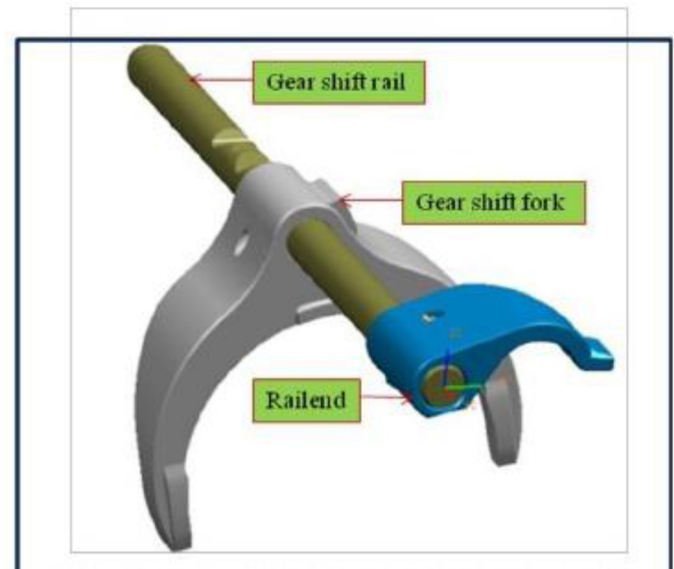


Figure 2. Representation of gear shift fork and rail end.

A linear variable differential transformer is fixed on to the shifter lever. 5 Speed manual gear box of different stiffness forks was taken as sample and the shift effort was recorded. The effect of fork stiffness can be an induced positivity in the shift system. The fork deflects and help to reduce the double bump peak. Data for various iterations were recorded and can be compared to get the optimum solution.

The key benefits of GSQA:

- From the Users Point of View:

1. System is easy to use and install in a vehicle ~ 30mins
2. Fast for acquisition and analysis, acquired data can be verified within minutes after completion of test
3. GSQA enables minimum data manipulation and maximizes engineers time spent evaluating data

- From the Managers Point of View:

1. GSQA has become a standard in the world of shift quality
2. GSQA will enable standardized reporting and interpretation across any group
3. Provides stable benchmarking and target setting
4. GSQA enables identification of shift quality problems. Enables most effective way to perform root cause analysis
5. Enables faster evaluations of vehicle gearshift quality saving TIME and MONEY
6. Cheaper than maintaining own in-house system e.g. the manufacturer will provide software upgrades for a

maintenance fee. More time spent testing and developing, rather than writing software

7. Able to request own specific measures within software relating to vehicle branding and evaluation

8. Software can be tailored to suit customers' in-house standards

OBJECTIVE

Today gear shift effort and feel are one of the primary criteria for evaluating a transmission. A major irritant is the double bump or 2nd hump force that a driver perceives during the gear shift. A number of parameters have been optimized to reduce the effect of double bump. Gear shift fork stiffness optimization is one such major measure to reduce the same.

The gear shift lever vibration and gear rattle can also be reduced with the gear shift fork stiffness optimization which is explained later in the paper. We innovatively optimize the gear shift fork stiffness and also reduce the weight using the optimization process.

The objective of the paper is :

- The gear shift fork stiffness of different material and manufactured through different process is optimized using the software for stiffness.
- Procedure of stiffness analysis and contact analysis are explained.
- The inputs and the constraints of modeling the shift fork are shared.
- The correlation of the gear fork stiffness to synchronizer double bump is established using GSQA.
- The reduction in the stress and weight of the gear shift fork using the stiffness analysis and contact analysis is explained.

FLOW CHART MODEL OF TRANSMISSION SHIFT SYSTEM

Figure 3 depicts a flow chart model of shift system with the synchronizer to help us interpret the concept of gear shift fork functioning and its correlation with other components.

Figure 4 helps us correlate the different components of a transmission and the effects of gear shift fork stiffness in reducing the double bump, gear rattle, lever vibration etc. as discussed later. The gaps between individual components depicted in the figure are an indication of a functional transmission. The importance of gaps indicated between the gear shift fork and the synchronizer sleeve are explained later in the paper.

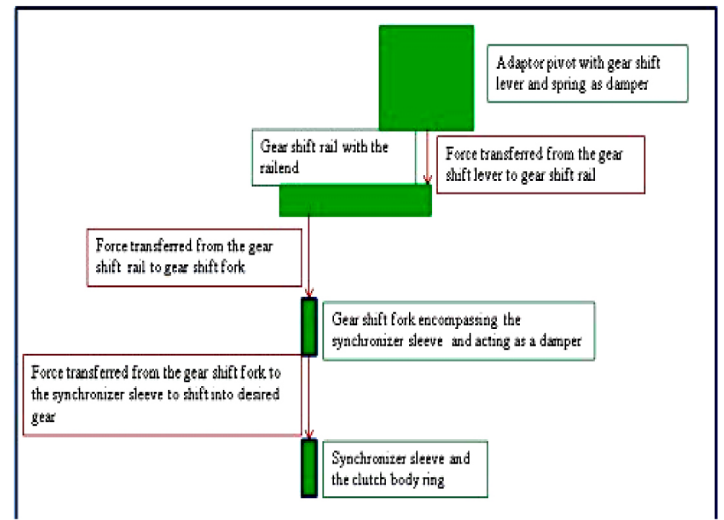


Figure 3. Flowchart to represent transmission shift system functioning.

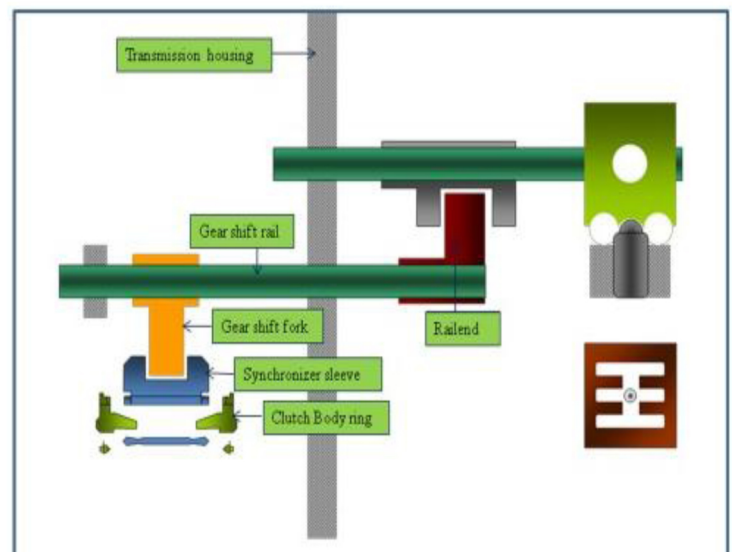


Figure 4. Schematic representation of shift system.

GEAR SHIFT FORK STIFFNESS

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 deflection should only occur in the elastic deformation zone of the fork material and this paper illustrates this phenomena.

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 symmetry 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. Both the pads shown in [Figure 5](#) have to come in contact at the same time so that the distribution of the synchronization force can take place uniformly and the stress concentration is less on both the pads.

The gear shift fork pad undergoes a finite number of repetitive cycles of loading thus subjecting it to fatigue failure. The stress on the fork should be lower than the endurance limit which makes the task of optimizing it for stiffness more difficult as the boundary condition for stress value gets lowered. As the gear shift fork is optimized for stiffness it tends to have an adverse impact on the stress that it can withstand.

Usually we have the issue of the gear shift fork breakage or unusual wear on one side of the prong. It is due to unsymmetrical gear shift fork pre-loading or due to unsymmetrical stiffness which is explained in this paper. The optimum value for stiffness was defined with the help of iterations, experience and benchmarking state-of-art gear boxes and it was set to be 1.2-1.5 KN/mm. Usually for low tensile strength materials like Aluminum we generally take it to be 1.5 KN/mm.

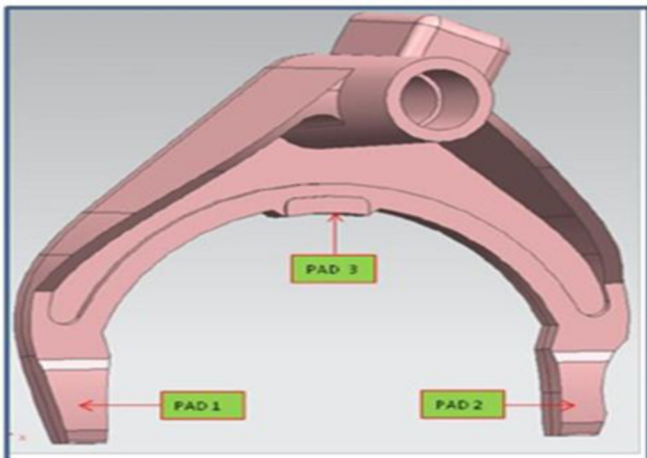


Figure 5. Gear shift fork pad configuration.

GEAR SHIFT FORK STIFFNESS CALCULATION

The gear shift fork stiffness simulation on UG NX Nastran requires many input parameters. The input parameter can be characterized into software and design parameter. The software input can be further classified into 3D modeling mesh size, density of the mesh at the fillets location, assembly modeling of the components with the various constraints etc. The design input can be material grade, gear shift fork loading pattern, stress and stiffness acceptance criteria etc based on the gear shift fork material and geometric design.

A few of the inputs discussed above are briefly described below and the effect they have on the gear shift fork simulation result:

3D modeling mesh size: If the mesh size is too large the deflection and the stress concentration distribution has lower magnification thus possibly missing the stress concentration points which may lead to failure. That parameter has been illustrated in [Figure 6](#) and [Figure 7](#). [Figure 6](#) represents a finer mesh model which results in a more accurate result and [Figure 7](#) represents a coarse model mesh which may solve quickly but will reflect inaccurate values or approximate values of stress resulting in an improper correlation.



Figure 6. Fine mesh model of Shift Fork.

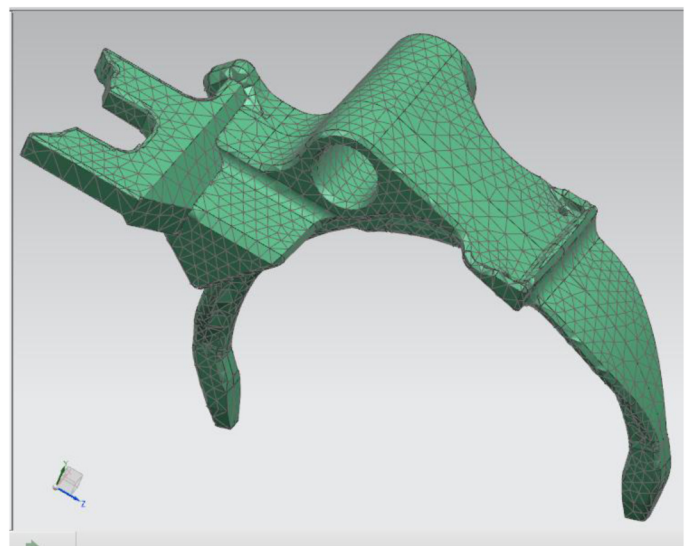


Figure 7. Coarse mesh model of Shift Fork.

Density of the mesh at cross-sectional change area e.g. fillets: The density of the mesh size should be altered with a cross-sectional change then the parametric distribution of the stress and the deflection is more discrete and helps us in