Vehicle Interface Challenges on Manual Transmission Application (PAP62)

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SUMMARY

The purpose of this Paper is to emphasize how certain vehicle characteristics that at first look seem unrelated to the Manual Transmission can cause undesirable issues on the Manual Transmission operation, performance and behavior. The Application of a same Manual Transmission on different vehicle design can bring unexpected results. These issues may be caused by Engine & Transmission Mounting stiffness, Suspension characteristics, Driveline Design, Driveline Stiffness, etc. These vehicle systems characteristics can potentially cause or aggravate issues as Transmission Gear Jump Out, Drive Rattle, Clunk Audible Noise and even jeopardize the Manual Transmission Gear Shift and contribute to cause Gear Clashing. Careful integration among systems and sub-systems must be considered. The detailed observation of the learnings acquired in past programs is rather important to prevent issues from happening on the Vehicle Development or Validation phases, reducing Development costs.

INTRODUCTION

This work offers evidences taken from several different experiments. Manual Transmission application should consider vehicle characteristics that at first look seem unrelated to the Manual Transmission, but in fact, can cause undesirable issues on its operation, performance and behavior. Learnings portrayed on next pages offer the opportunity to foresee several potential issues during development and production phase and use them as a preventative action.

1. External Influences on Transmission Drive Rattle: Suspension & Engine.

The following measurements performed on two pick-ups (fig.01) of the same brand with different Transmission Drive Rattle behaviors is useful to emphasize how external factors can attenuate or exacerbate Manual Transmission Drive Rattle. Manual transmission Drive Rattle or Gear Rattle is an NVH (noise, vibration, and harshness) phenomenon. It is induced by repetitive impacts on loose (unselected) gear wheel teeth by their corresponding driving pinions.

Vehicle characteristics: The vehicle I20 exhibits better Driveline behavior than NS10. Both vehicles are Mid Size Pick ups trucks powered by a Gas Engine, SOHC (I20) and DOHC (NS10). Both are 4x2 with longitudinal Powertrain & Driveline. Each one was equipped with a different rear suspension design.

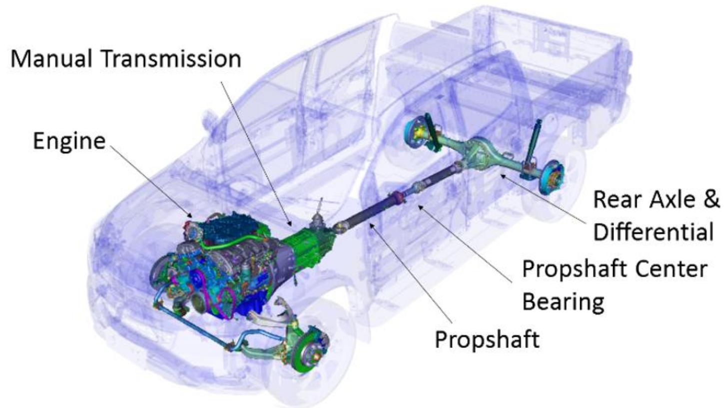


Fig.01: Example of Pick-up Truck Longitudinal Powertrain and Driveline architecture.

1.1 Torsional Vibration Measurements

Torsional vibrations excite the gearbox (fig.02), causing drive rattle. In order to measure such vibrations, three magnetic sensors were installed in each vehicle driveline as shown below. Data recorded by a special equipment were used to compare vehicles and correlate their subjective evaluation in terms of drive rattle noise.

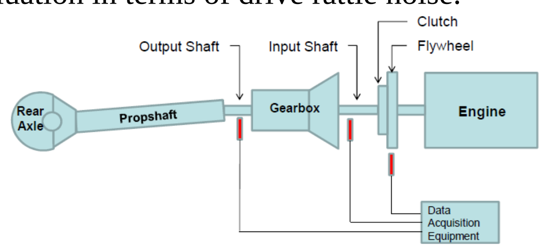


Fig.02: Torsional vibration installation areas.

1.2 Engine Torsional Vibration: Differences between NS10 & BOB I20

NS10 (SOHC/FLEX) engine presents more torsional vibration than I20 (DOHC/E0). That is due to:

• Higher compression ratio.

• Alcohol fuel causes sharp combustion pressure peaks.

Remark: In both measurements, the vehicles are equipped with the same Manual Transmission (FIG.03).

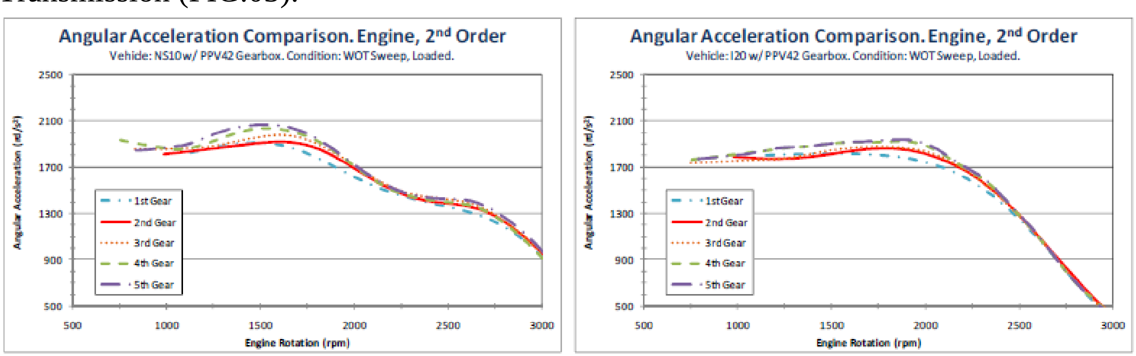


Fig.03: Engine torsional vibration measurements.

1.3 Input Shaft Torsional Vibration: Differences between NS10 & BOB I20

Transmission input shaft of the NS10 presents higher torsional vibration amplitudes in some gears and sharper resonances than in the I20 transmission (fig.4). Remark: In both measurements, the vehicles are equipped with the same Manual Transmission.

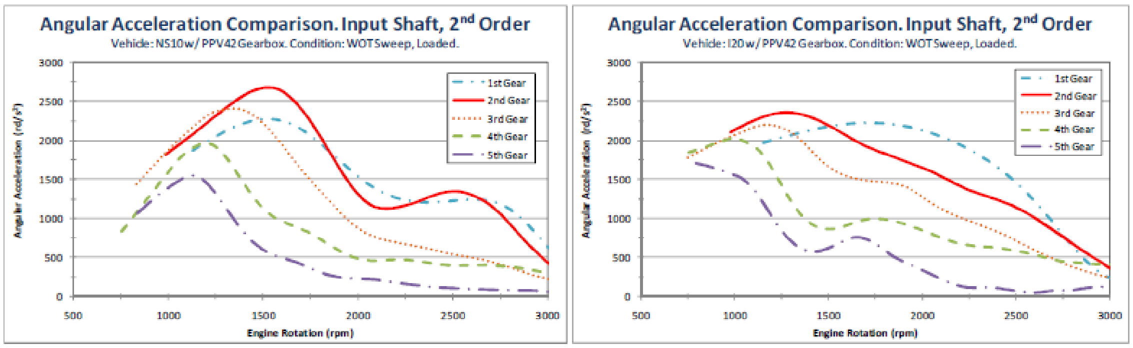


Fig.04: Input shaft torsional vibration measurements.

1.4 Output Shaft Torsional Vibration: Differences between NS10 & BOB I20

Same behavior noticed on transmission input shaft: NS10 presents higher torsional vibration amplitudes in some gears and sharper resonances than in the I20 transmission. Remark: In both measurements, the vehicles are equipped with the same Manual Transmission.

1.5 Rear Suspension Characteristics and Payload influence on Drive Rattle

Vehicle I20, Input Shaft measurements.

Payload changed the first torsional resonance frequencies and amplitudes on the I20 vehicle. Besides, the vibration peak around 1600erpm had its amplitude increased. The second vibration peak increases noise rattle so, in other words, customer will hear the Drive Rattle for a longer rpm range (fig05).

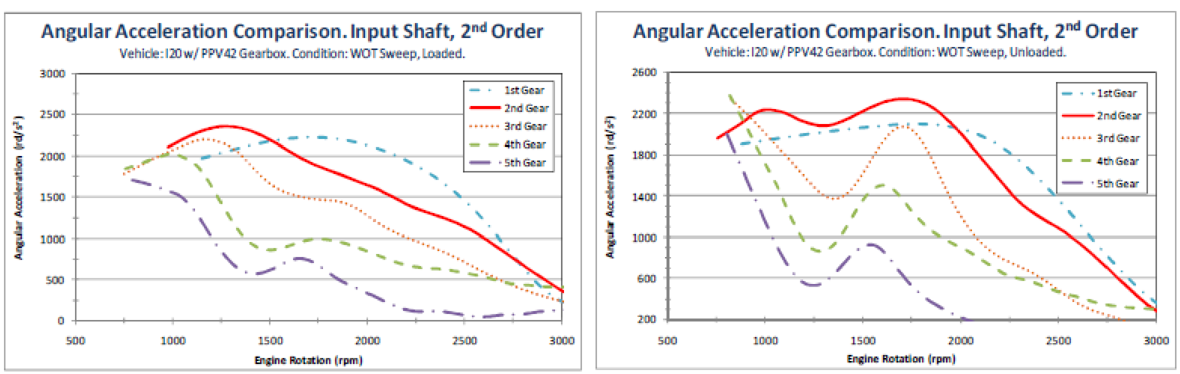


Fig.05: Transmission Input Shaft readings on I20 and NS10 vehicles.

Vehicle I20, Output Shaft measurements:

Same behavior noticed on input shaft: payload changed the first torsional resonance frequencies and amplitudes and increased the amplitude of the vibration peak around 1600erpm.

It is important to notice that payload:

• changes angles of the propshaft, which increases vibration levels;

• stiffens rear suspension spring, by reducing gaps between its leaves. That changes torsional stiffness of the system (fig.06).

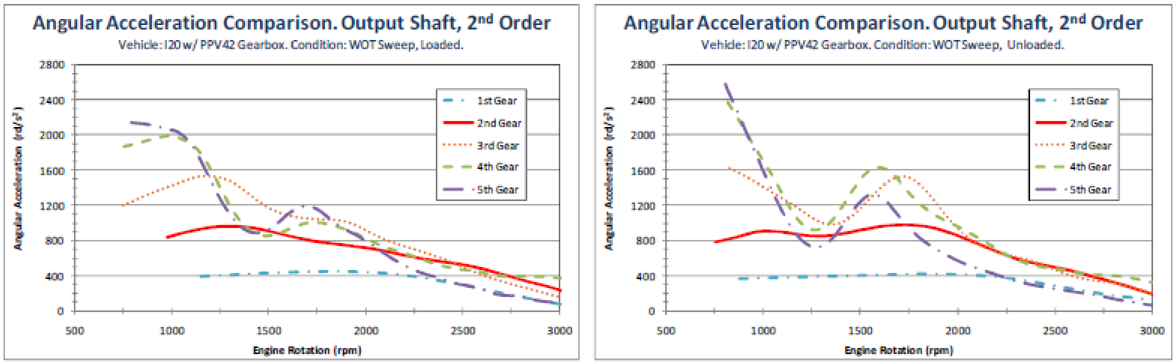


Fig.06: Transmission Output Shaft readings on I20 and NS10 vehicles.

When vehicle is loaded, rear springs stiffness is higher (more leaves get in contact to counter act vertical load). Torsional stiffness of the rear springs also increases and that changes Rear Axle pitch behavior when torque is applied by the propshaft. In other words, rear springs affect torsional stiffness of the drivetrain system (fig.07, 08, 09, 10).

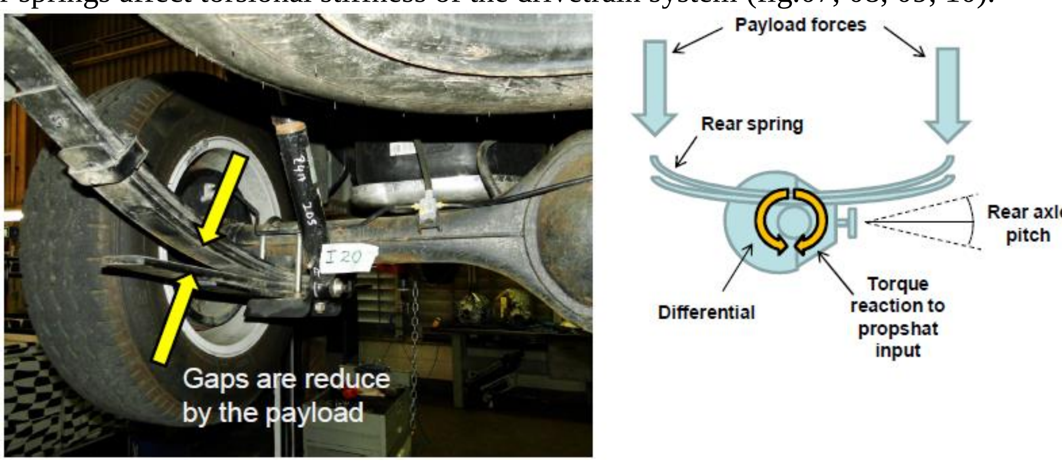


Fig.07: Rear suspension springs reaction to loads

Influence of Payload: Vehicle NS10, Output Shaft.

On the NS10 vehicle, it has not been noticed a strong influence of the vehicle load on torsional vibration behavior of the driveline. That may be caused by the completely different leaf springs installed in that vehicle and propshaft angles.

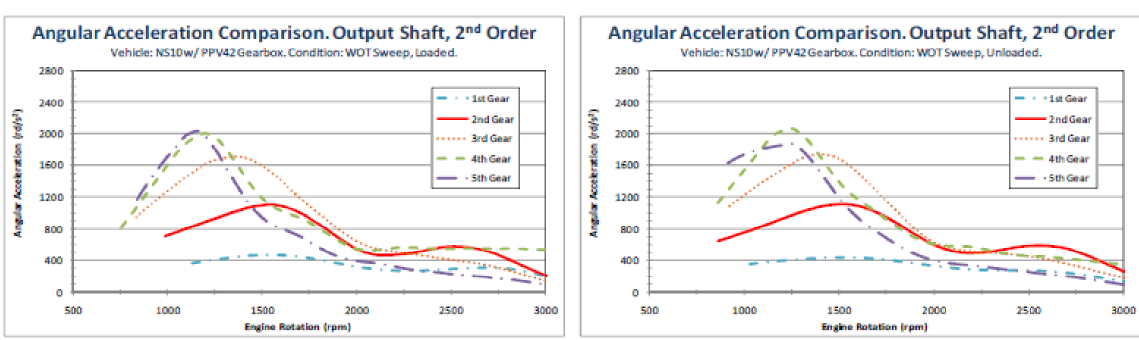
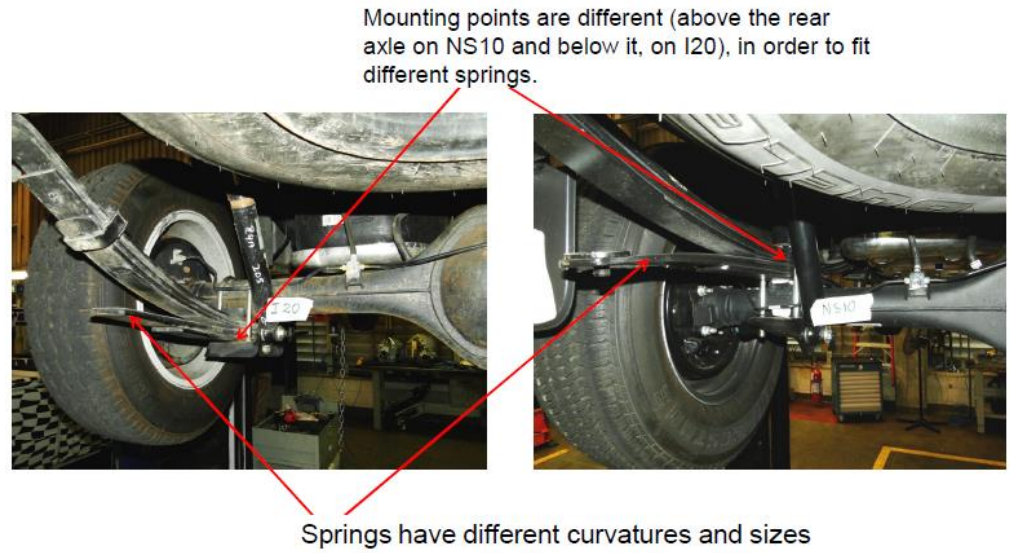


Fig.08: Payload influence on torsional vibration



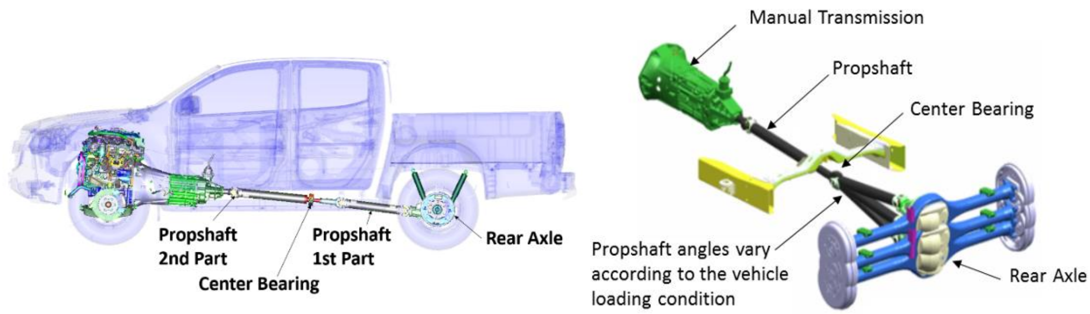


Fig.09: The Pick-up Truck Driveline and Rear Suspension. The Rear Suspension Bounce and Rebound induces different suspension geometry and leads to Suspension Stiffness variation.

Vehicle	Condition	Propshaft Angle in Degrees (in relation to ground) First part	Second part
I20	Loaded (610Kg + 3 passengers)	3.9	1.3
I20	Unloaded (3 passengers)	2.6	5.6
NS10	Loaded (610Kg + 1 passenger)	6.5	2.1
NS10	Unloaded (1 passenger)	4.9	6.3

Main factors which cause different propshaft angles are:

- intermediate support of the propshaft (see picture above);
- different rear springs;
- payload capacity and distribution.

Fig.10: Propshaft angles given a vehicle configuration

1.6 Takeaway

Gearbox design is not the only factor than influences gear rattle noise. Engine input, Rear Suspension Design, Loading, Propshaft angle and Rear Axle also play an important role. Therefore, when it comes to Drive Rattle comparison among two or more vehicles, Gearbox Design and Vehicle characteristics should be taken into consideration. The same rule should also be taken into consideration at the start of the vehicle design, so transmission and vehicle features can carefully be balanced against vehicle requirements. This balance is essential not only to achieve the requirements but also to achieve it at an affordable cost.

2. Driveline Stiffness influence on Manual Transmission Shift Quality

Objective experiments have indicated that the Half Shaft Stiffness can affect the Manual Transmission Shift Quality. Either Front Wheel Drive (FWD) or Rear Wheel Drive (RWD) are subjected to the same rule. High Driveline Stiffness brings the potential of inducing a greater effort to disengage the gears due to the fact the half shafts have the property of accumulating Torsional Elastic energy during drive mode (positive torque) and the sudden release of this energy in case of sportive maneuvers such us fast gearshifts.
This sudden release of accumulated Torsional Elastic energy comes into play exactly at the moment the Clutch is released, jeopardizing the Manual Transmission Gear Shift Sleeve movement from one gear to the next, increasing thus the Disengagement Shifting effort.
This phenomenon can also contribute to jeopardize the synchronization process of the next gear and result in Gear Clashing. The sequence of events is shown at fig.11, 12,13.

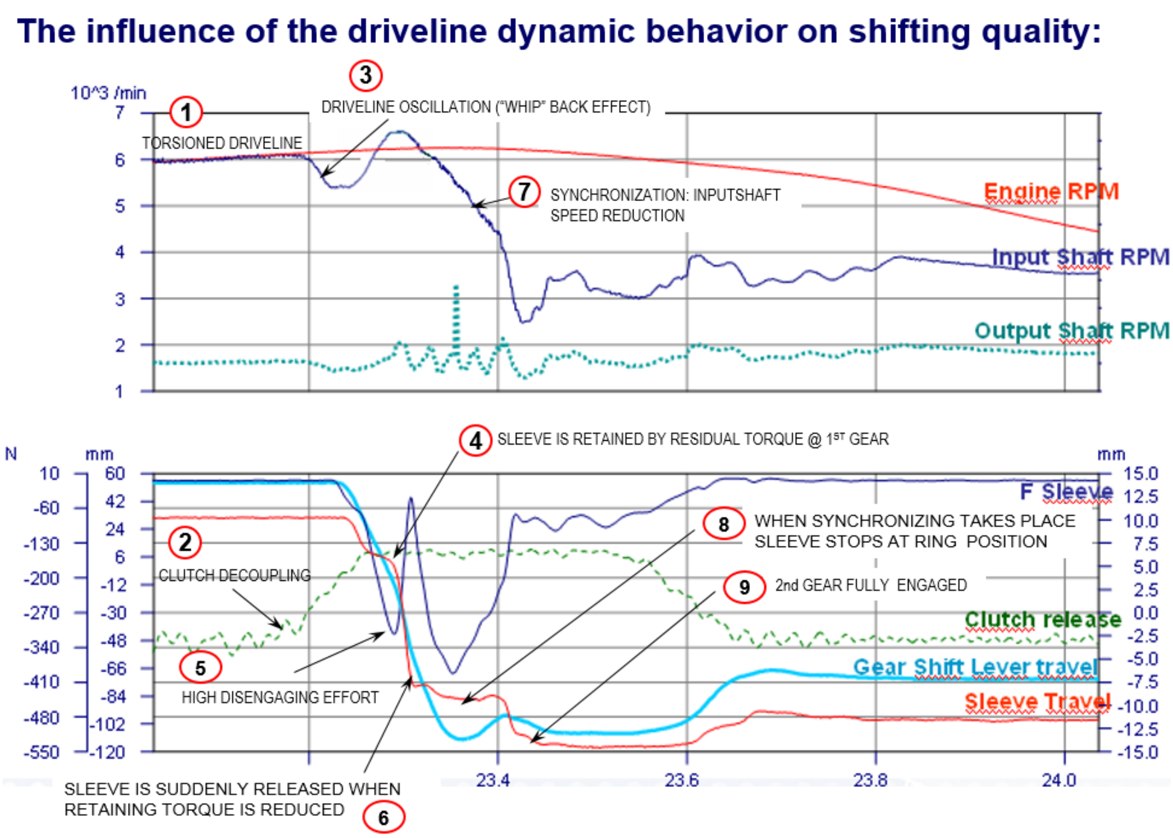


Fig.11: Objective Readings on Manual Transmission, Clutch, Shifter and Engine during sportive Gear Shifting.

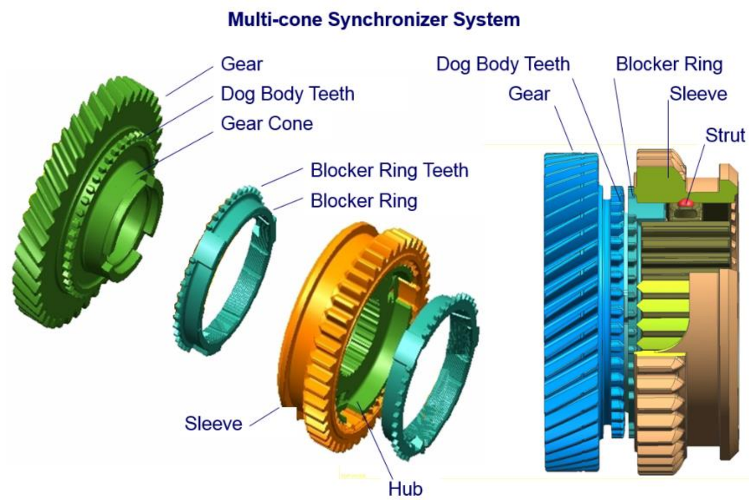


Fig. 12: Manual Transmission Synchronizer Components.

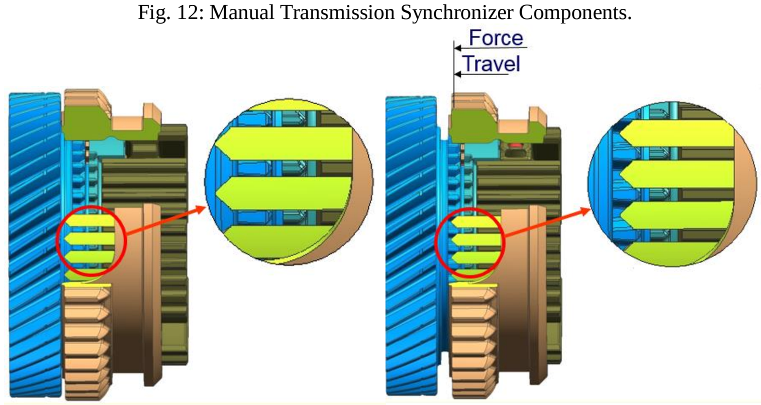


Fig. 13: Manual Transmission Synchronization initial steps during Gear Disengagement.

3. Driveline Stiffness influence on Manual Transmission Clunk Noise

Clunk noise is a loud noise attributed to total powertrain response to torque oscillations in the system [2]. All backlashes in the driveline systems are the main contributor to increase the clunk noise of the vehicle [3]. Examples of backlash sources in the driveline system are the slip yoke at the propeller shaft interface with the transmission and the transfer-case output shaft (fig.14).

When the driveline suddenly releases its elastic torsional energy, it generates an excessive clunk event. A rapid de-clutch quickly removes drive torque, which causes a progressive closure of all the lashes in the system as drive shafts release their torsional energy. This action evokes a low frequency oscillating response of lash closure / openings within the gear sets. The Oscillation results in multiple metallic audible clunk events within the Cabin.

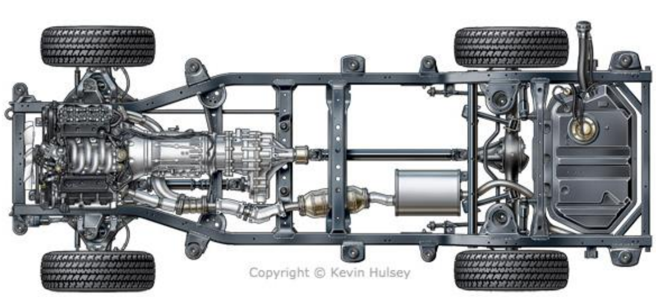


Fig.14: Vehicle drivetrain general view

The clunk response depends on the severity of the maneuvers. Determinant factors include drivetrain and suspension spring rate, system lashes, stiffness and damping. The proper design, considering reduction at acceptable/feasible levels of lash between these matching components, may help to attenuate the noise.
Looking over the rear axle, overall lash plays a role on the clunk. Limiting and reducing backlashes within feasible limits in the vehicle driveline (e.g. axle shaft spline to differential case interface backlashes and gears backlashes) will contribute to reduce clunk levels. Gear meshing noises or even assembly issues caused by possible dimensional interferences are examples of collateral effects caused by excessive reduction of backlash.
Wave springs or spring washers installed with differential gears are proven to be effective in attenuating clunk, not only by decreasing levels of lash, but also by creating a noise dampening effect. Axle shaft diameters (fig. 15) affect torsional modes as well and contribute to the clunk. A proper diameter design may help in clunk attenuation.

Fig. 15: Axle shafts have the property of accumulating the Torsional Elastic Energy.

Suspension wind-up is another dimension to take into account. If an increase in suspension stiffness is not possible, rear axle spring seat repositioning may alleviate propeller shaft to rear axle angles and reduce wind-up levels [1]. Staggered shocks associated to spring seat reposition also help to damp wind-up movement.
There is also an influence of Final Drive Ratio on Clunk: as higher the FDR is, higher torque multiplication will be available in the driveline. More energy stored in Axle shaft will result in higher clunk events.

4. Mounting influence on Manual Transmission Gear Jump Out

The following data offers evidences on the decisive contribution of Transmission Mountings characteristics to Gear Jump Out phenomenon. The Gear Jump Out event is the subtle, unexpected and unintended disengagement of the gear in which the vehicle is driving into. Its occurrence requires a specific abusive maneuver on gravel road.
The experiment focused on three different pickup trucks:

- Vehicle #A: Gas Engine, Manual Transmission, 4x2, Single-Cab, Leaf Spring Rear Suspension.
- Vehicle #B: Diesel Engine, Manual Transmission, 4x2, Single-Cab, Leaf Spring Rear Suspension.
- Vehicle #C: Diesel Engine, Manual Transmission, 4x2, SUV, Multi-link Suspension.

Vehicle A and C do not exhibit the issue. The issue is only apparent on vehicle B.

4.1 Data acquisition results.

The acceleration measured on Frame, Transmission Case and Shifter Lever Knob indicates diverse response for each vehicle. The vehicle 'B' emerged with the higher Shifter Lever Knob acceleration (25 Gs), in comparison with 6 Gs (A and C). The data also indicated the vehicle 'B' Transmission Mounting induces higher Frame acceleration (1.8 Gs) and higher Gearbox Case acceleration (4 Gs) in comparison with vehicles A & C. The higher Shifter Lever acceleration on the gear disengage direction offers one important factor to explain the Gear Jump Out (fig.16).

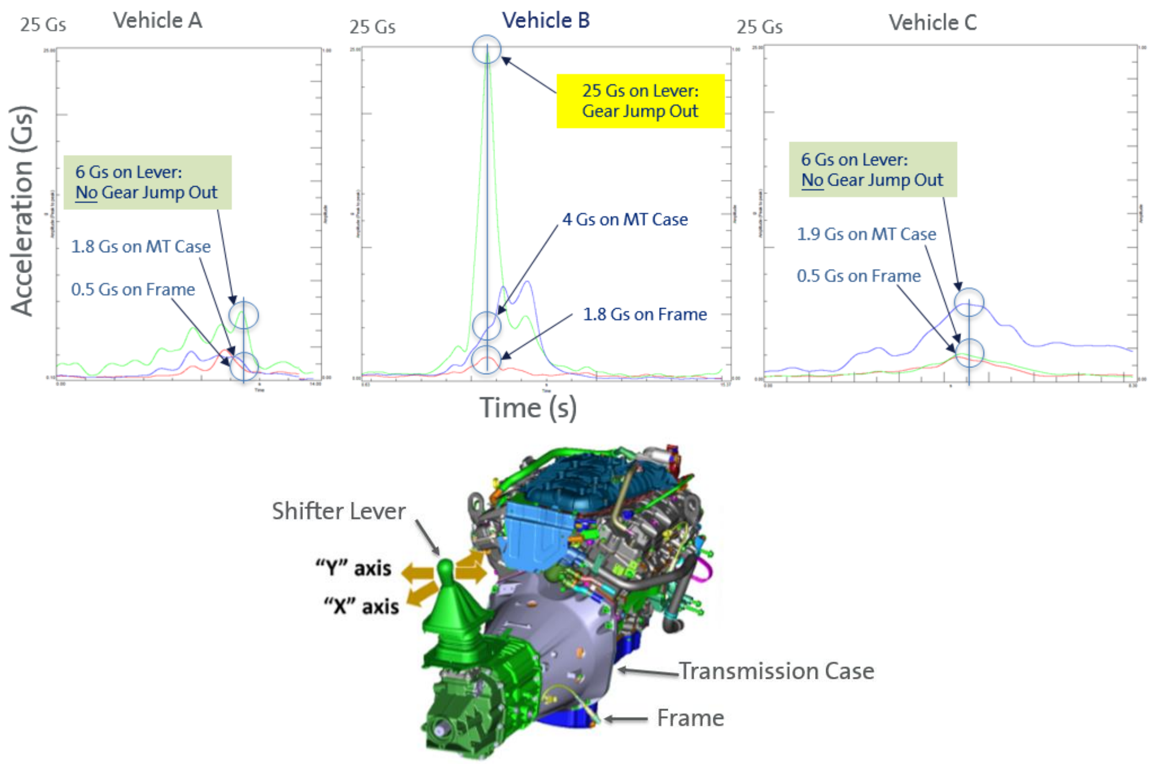


Fig. 16: Acceleration measurement results taken on Frame, Transmission Case and Shifter Lever Knob on 'A', 'B' and 'C' vehicles.

Other phenomenon simultaneously takes place to contribute to Gear Jump Out: The vehicle Rear Suspension allows rear wheels to hop (fig.17). This results in torque fluctuations on the Driveline. This fluctuation jeopardizes the Transmission Sleeves Back Tapper operation (see fig. 18). This will collaborate to reduce the Gear retention and ultimately result in the Gear Jump Out.

Fig. 17: Rear Wheels Hop Out observed during abusive maneuver at Gravel Road.

The results of the observations allow the following chain of events:
1) Vehicle coupling frequency excites the Lever into Disengagement direction and accelerates the Lever to Gear Jump out which is different from application to application.
2) The Rear Suspension Hop results in torque fluctuations and powercube motion, which triggers the gear jump out.

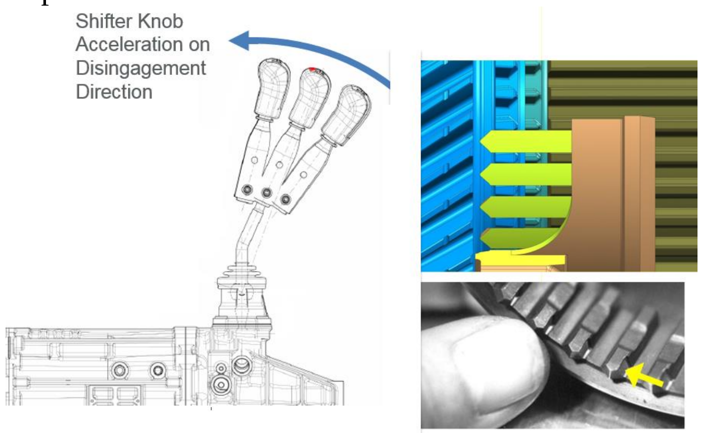


Fig. 18: Two simultaneous factors merge together to lead to Gear Jump Out: High Acceleration (25 Gs) induced at the Shifter Lever Knob in the disengagement direction and the Rear Wheel Hop Out deactivate the Manual Transmission Back Taper.

4.2 Takeaway

The results above demonstrate that Gearbox Gear Jump Out can be precipitated by vehicle factors: Rear Suspension Design, Mounting characteristics, type of track, type of maneuver play an important role.

CONCLUSION

Factors beyond the Gearbox design can affect the Manual Transmission deliverables, meaning that the vehicle application characteristics have the potential of inducing particular effects on Manual Transmission NVH (Noise, Vibration and Harshness), Shifting Quality and behavior.
This conclusion is fundamental for an adequate selection of the Transmission & Vehicle Design characteristics early on the Design Phase. This conclusion is also helpful for a fair and balanced comparison among competitor vehicles. This work purpose is to emphasize that a well-made transmission design deeply depends on broad knowledge on the vehicle application.

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