Reduction of Handball Impulse Forces produced in Synchromesh Gear Boxes by Parametric analysis of Synchronizer Pack Design

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Abstract - *Bulk of the heavy vehicles in use operate on manual transmissions with synchromesh type gear boxes. Here the lack of high speed performance necessities and frequent service requirements resulted in persistent usage of less complex Single and Dual cone synchronizers. However the greater Torque-capacity requirements and ever increasing focus on Ergonomic comfort for the driver have put the spotlight back onto synchronizer technologies. This document deals with the parametric value changes (like cone angle, shift forces, friction material etc.,) that can bring in more comfort while operating manual transmissions with synchronizers and also the possible use of Triple cone synchronizers for the first time in commercial Vehicles.*

Key Words: M**anual transmissions**, **Single and double cone synchronizers**, **Ergonomic comfort, Triple cone and Cone Angle, Shift Forces** and **Friction Material.**

1. INTRODUCTION

Synchronizer technologies have long been in use, in manual transmissions, albeit with different companies having their own technique of synchronizing, to suit their own transmission systems. More robust and complex synchronizers are used in cars/light vehicles, where compactness and efficiency at high speeds are crucial. However, in commercial vehicles, the synchronizers are limited to less complex single cone type synchronizers mostly and sparsely, double cone synchronizers for low speed gears.

In this paper we emphasize on parameters that have predominant impact on impulse forces generated. Impulse forces are a sum of 1) Product of Shift force applied and the Synchronization time and 2) Reaction forces offered by the gear box components during the gear shifts. The reaction forces change with the each gear box and the gear that is engaged. But they constitute only a fraction of the impulse forces generated. Hence we look at the primary cause that is the shift force applied. By reducing the shift force applied at the handball, we can decrease the effort of the driver and also the impulses the driver would experience. But reducing the shift effort would decrease the friction torque necessary in order to achieve the synchronizing required. Hence, we look at the parameters involved in the friction torque production and explore the possibilities of achieving the required friction torque by altering these parameters with a reduced shift effort for a gear shift.

2. EXPERIMENTATION PROCEDURE

2.1 *Equipment and Software requirements*

A 6 Speed (+Reverse) 700-Nm torque capacity gear box of a medium commercial vehicle is considered and its synchronizer pack design is taken for the parametrical analysis. The analysis is done using Synchro Prediction Software.

2.2 *Parameters involved*

The friction torque is a function of number of friction cones in the synchronizer pack (n), co-efficient of friction (μ) of the friction lining used on the synchro cones, effective diameter (d_m) of the friction cone used, shift force (F_a) applied and cone angle (α).

Number of cones in the synchronizer pack is determined by the friction torque requirements, affordable pack length and the complexity allowed. Co-efficient of friction is a constant, for a given friction material, however its variance with temperature gradient has to be considered when analyzing the synchronizer performance. Effective diameter of the synchro cone is limited by the gear size and the centre distance between the main shaft and lay shaft. Cone angles are limited by the locking torque (premature locking of the synchro cones). Here, the friction material chosen is crucial because, each material has its own co-efficient of friction. Lower cone angles increase the friction production and greater the friction greater the chance of premature locking to occur. In the gear box chosen, the friction material is Molybdenum (Mo) and cone angles are at 6.5° for single cones and 9° for double cones.

2.3 Approach

Friction material choice is persisted with molybdenum, because changing it would require changes in the transmission fluid used, no. of grooves on the synchro ring and other factors that account for lubrication and cooling of synchro rings. For the Molybdenum synchro cones, the minimum cone angle should be 6.5◦ to avoid premature locking. The centre distance between the shafts available in this gear box is 145 mm. The mean effective diameter of the synchro cones is at 130 mm. Thus there is room for potentially increasing the diameter to 180mm after accounting the necessary room for the sleeve blocker ring teeth etc. The other option is to increase the no. of cones. But this increases the no. of components, synchronizer pack length and the complexity of the synchro pack with all the linking mechanisms to keep the synchro rings in place. They also increase the overall length and production cost of synchronizers.

3. MATH

The equation for friction torque calculation is considered and the torque produced with the available parametric values is calculated. The obtained value is taken as a bench mark and is used to optimize the function parameters so as to reduce the shift effort without compromising the friction torque production.

3.1 Equations

Friction Torque,

$$T_R = \frac{n\mu d_m F_a}{2sin\alpha} \quad (1)$$

(n) - Number of friction cones
(μ) - Co-efficient of friction
(d_m) - Effective diameter of the friction cone
(Fa) - Shift force applied and
(α) - Cone Angle

3.2 Units

(TR) - Newton-metres (N-m)
(dm) - millimetres (mm)
(Fa) - Newtons (N)
(α) - degrees(°)

4. ANALYSIS

Using (1), several iterations of simulation are done with

a) Cone angle (α) values varying from 9° to 8.5°,
b) Effective diameter varying from 130mm to 180mm,
c) (a) and (b) in combination,
d) Number of friction cones increased from 2 to 3 (with original dimensions),
e) 3 Friction cones with modified dimensions as in (c).

4.1 SIMULATION

Ricardo Synchro Prediction Software is used for estimating the Impulse generation from the gear box that is felt by the driver on the handball of the shift fork. All other synchronizer pack parameters like the pack length, groove depths, width, and number of grooves are taken into account. Also some of the transmission parameters like the number of teeth on various meshing gears and also the fork lever ratio. The characteristic impulse curves are as in the figures given below.

First the existing design of synchronizer pack is evaluated for the impulses predicted from it with that of average rated (7.5 Points) and Target rated (8 Points) impulse simulations. Observations prove the design is above optimum rating value. The simulation is continued further with several iterations of effective diameter (d_m) varied in steps of 0.02mm and cone angle (α) varied in steps of 0.1°.

4.2 OBSERVATIONS

The impulse data obtained is observed to be following a steady decrease with individual iterations while in combination they exhibit a random but drastic decreasing trend. An additional friction cone is added and the above iterations are applied in tandem to the added cone. This gives a very pronounced reduction in impulse generation. Fig. 6 and Fig. 7 depict the comparison of shift forces required in the original synchronizer pack design and the modified design. The reduction in the shift force required is nearly 23%.

4.3 PROPOSALS

- Increasing the diameter by 14% gives a shift force reduction of nearly 12%.
- Decreasing the cone angle by 0.5◦ reduces the shift effort by 17%.
- Use of an additional friction cone reduces shift force requirement by 33%.
- Additional friction cone in combination with first two proposals gives shift force reduction of 45%.

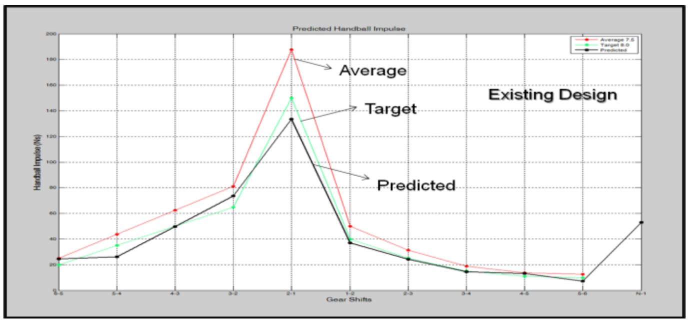

Fig -1: Impulse curves of existing synchronizer pack design, Predicted Vs Average and Target rated Impulse curves for the given model

Handball Impulse (Ns) vs. Synchronisation Time

Sync. Time (s)

	0.05	0.1	0.15	0.2	0.25	0.5	0.75	1
6-5	14.4866	15.1398	15.7930	16.4461	17.0993	20.3653	23.6312	26.8972
5-4	17.3398	17.9172	18.4946	19.0721	19.6495	22.5367	25.4238	28.3110
4-3	35.4553	36.3833	37.3114	38.2395	39.1676	43.8081	48.4486	53.0891
3-2	53.2329	54.5516	55.8703	57.1890	58.5077	65.1011	71.6946	78.2880
2-1	98.9384	101.1839	103.4295	105.6751	107.9206	119.1485	130.3764	141.6042
1-2	44.8507	43.5320	42.2133	40.8946	39.5759	32.9825	26.3890	19.7956
2-3	29.8702	28.9421	28.0140	27.0859	26.1578	21.5173	16.8769	12.2364
3-4	17.9285	17.3511	16.7736	16.1962	15.6188	12.7316	9.8444	6.9572
4-5	17.1601	16.5069	15.8537	15.2005	14.5473	11.2814	8.0154	4.7495
5-6	10.0915	9.6061	9.1207	8.6353	8.1500	5.7230	3.2961	0.8691
N-1	66.5375	64.2919	62.0463	59.8008	57.5552	46.3273	35.0995	23.8716

Fig - 2: Handball Impulse values for all gear shifts at different synchronization times

Handball Impulse (Ns) vs. Synchronisation Time

		0.05	0.1	0.15	0.2	0.25	0.5	0.75	1
Designed model	2-1	98.9384	101.1839	103.4295	105.6751	107.9206	119.1485	130.3764	141.6042
	1-2	44.8507	43.5320	42.2133	40.8946	39.5759	32.9825	26.3890	19.7956
1. Cone Diameter Increase from 131.5mm to 150mm	2-1	86.7360	88.7046	90.6732	92.6418	94.6104	104.4535	114.2966	124.1397
	1-2	39.3191	38.1630	37.0070	35.8509	34.6949	28.9146	23.1344	17.3541
2. Cone Diameter Increase + Cone Angle decrease by 0.5°	2-1	81.9538	83.8138	85.6739	87.5340	89.3941	98.6944	107.9948	117.2952
	1-2	37.1512	36.0589	34.9666	33.8743	32.7820	27.3204	21.8589	16.3973
3.Triple Cone Usage	2-1	65.9589	67.4560	68.9530	70.4500	71.9471	79.4323	86.9176	94.4028
	1-2	29.9004	29.0213	28.1422	27.2631	26.3839	21.9883	17.5927	13.1971
4.Triple Cone in combination with 1 & 2	2-1	54.6358	55.8759	57.1159	58.3560	59.5960	65.7963	71.9966	78.1968
	1-2	24.7675	24.0393	23.3111	22.5829	21.8547	18.2136	14.5726	10.9315

Fig - 3: Handball Impulse values for 1st and 2nd gear shifts at different synchronization times for the proposed modifications

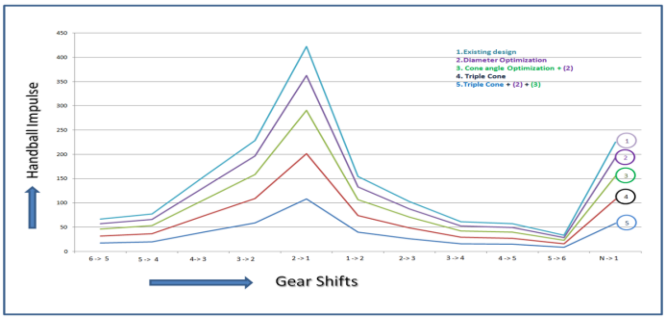

Fig - 4: Impulse curves for all the proposed modifications

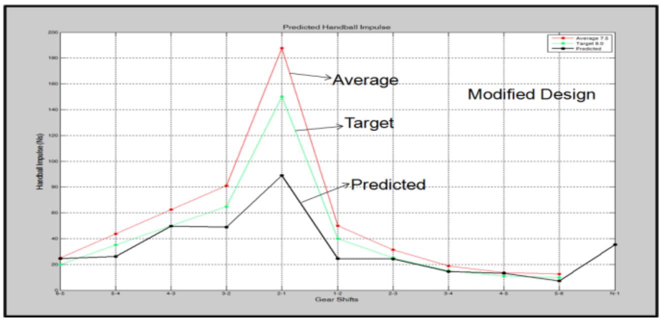

Fig - 5: Impulse curves of modified synchronizer pack design, Predicted Vs Average and Target rated Impulse curves for the new model

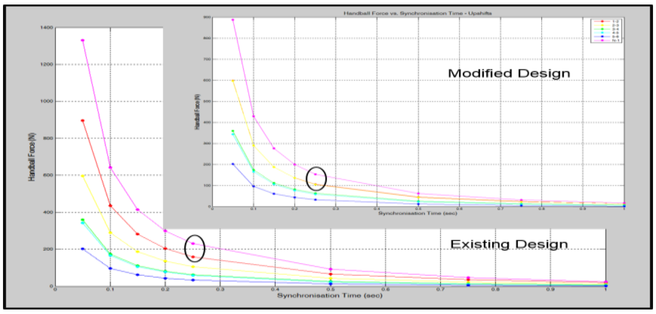

Fig - 6: Shift force comparison in Upshifts

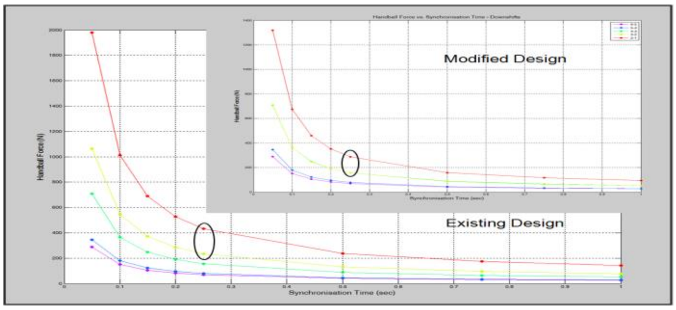

Fig - 7: Shift force comparison in Downshifts

By using the above proposals the handball impulses felt by the driver in each gear shift can be reduced proportionally.

5. CONCLUSION

Modern day Ergonomic standards give paramount importance to the driver's effort during the ride and his/her comfort level. As manual transmissions are still a major choice in drive trains of commercial vehicles and with the advent of *Dual Clutch Transmissions (DCTs)*, synchronizers are assured a long life. Hence more efficient synchronizers with little to no strain on the drivers are necessary.

The above proposals, though pertain to the chosen gear box, could efficiently be used in any gearbox in similar ways to obtain results to the like obtained here. However, after the design modifications, there is a necessity to study the heat generation patterns and make appropriate modifications (inclusion of additives) in the transmission fluid to be used. Also necessary coatings are to be applied on friction surfaces to provide enough lubrication and cooling to the rings.

Triple cone synchronizers considerably increase the complexity and also the synchronizer pack length (thereby the gear box size), but with continuous advancements in technology, it can easily be overcome. Thus with repeated mathematical analysis and subtle design changes, handball impulses can be reduced and the driver comfort level can easily be enhanced.

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