THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 7, 2024, 5-8

PARAMETRIC STUDY OF ENGAGEMENT PROCESS OF SHIFTING MECHANISM IN AN AUTOMOTIVE GEARBOX

Esmam Zahan and Ali Farokhi Nejad *
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor, Malaysia.
* Corresponding author: farokhi@utm.my

ABSTRACT

This paper represents a comprehensive simulation study using Amesim to analyze the effects of 14 dynamic parameters on the performance of a gearbox synchronizer. A data set of 128 simulations was created systematically, with each simulation assessing different parameter configurations. This study primarily aimed to evaluate the impact of these parameters on synchronization time, engagement time, output torque, and detent force. Key findings from the simulations highlighted optimal parameter settings that led to the most efficient synchronizer performance, including the minimum synchronization time, least engagement time, maximum output torque, and minimal detent force required. This data can be used to optimize the design of the synchronizer according to targeted application, with efficient fuel consumption and power optimization.

KEYWORD

Synchronizer mechanism, Gear Shifting, Transmission system, Lump Dynamic analysis, shifting time

INTRODUCTION

Various modifications have been implemented on the transmission system to provide greater performance and efficiency of the vehicle. The gear shifting mechanism plays one of the most significant roles in the transmission system, directly influencing the behaviour, power and fuel consumption of the vehicle.

Development and optimization of the gearbox synchronizers have been a highlight for the automotive research. Previous studies (Zhang et al., 2022; Nejad, 2019) include development of the dynamic models of the synchronizer while, numerous research (Guo et al., 2023; Liu et al., 2017) involve with simulation and understanding of different parameters influencing the dynamic performance of the synchronizer. All in an attempt to improve synchronizer performance and efficiency.

Despite advancements, the engagement process in automotive gearboxes still faces challenges related to shifting time, smoothness, and energy efficiency. These aspects are closely related to the fuel consumption, durability, shifting comfort as well as environmental impact. The relations between the dynamic parameters and the engagement process are crucial to be investigated for further development and optimization. Previous research has often focused on individual parameters or specific aspects of gearbox performance. However, a comprehensive parametric study that demonstrate the overall interaction of the parameters and influence on the shifting performance is yet to be studied. Such an exploration is essential for more efficient gearbox design.

The study aims to conduct a parametric study to explore how various dynamic factors influence the gear shifting performance in a gearbox. It also includes the use of 1D Lump Dynamic simulation software to simulate the synchronization process, enabling the assessment of these factor’s effects on gear shifting time, torque output, and energy usage.

MATERIAL AND METHODOLOGY

The synchronizer engagement process involves 8 distinct steps: free flight, start of angular velocity, velocity synchronization, turning the synchronizer ring/disengagement, second free flight, start of second bump, turning the gear, and final free flying. Initially, the shifting sleeve and synchronizer hub have the same angular velocity, while the clutch body ring rotates differently. As angular velocity begins, the sleeve slides axially, creating frictional torque. Following that, the axial force increases, aligning the velocities of sleeve and synchronizer ring. With the frictional forces reduced to null, disengagement occurs, enabling the synchronization. Finally, the sleeve meshes with the clutch gear, achieving complete engagement with synchronized rotation and zero axial force. Figure 1 shows a physical model of a single cone synchronizer.

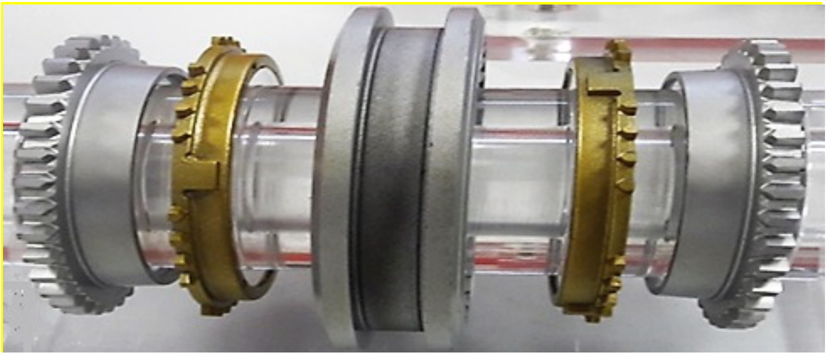

Figure 1: Model of a single cone synchronizer (Nejad, 2019).

To comprehensively understand and optimize synchronizer performance, a dynamic model of synchronizer has been simulated within Simcenter Amesim, a 1D Lump Dynamic Simulation software, as shown in Figure 2. This model leverages the software's advanced graphical interface and multi-physics libraries to intricately simulate the interactions between synchronizer components during gear shifts. The model represents crucial components such as the synchronizer ring, strut detent assembly, and shifting sleeve. By integrating key parameters and varying them within specified ranges, the Amesim model enables in-depth analysis of their individual and collective effects on synchronizer responses. Through the Design of Experiment method by Design Expert, 128 distinct datasets of 14 parameters were generated, allowing for the exploration of parameter influences on synchronization time, output torque, engagement time, and detent contact force, as shown in Table 1. Following the analysis of this data facilitates the identification of significant parameter configurations to enhance synchronizer performance and overall transmission efficiency.

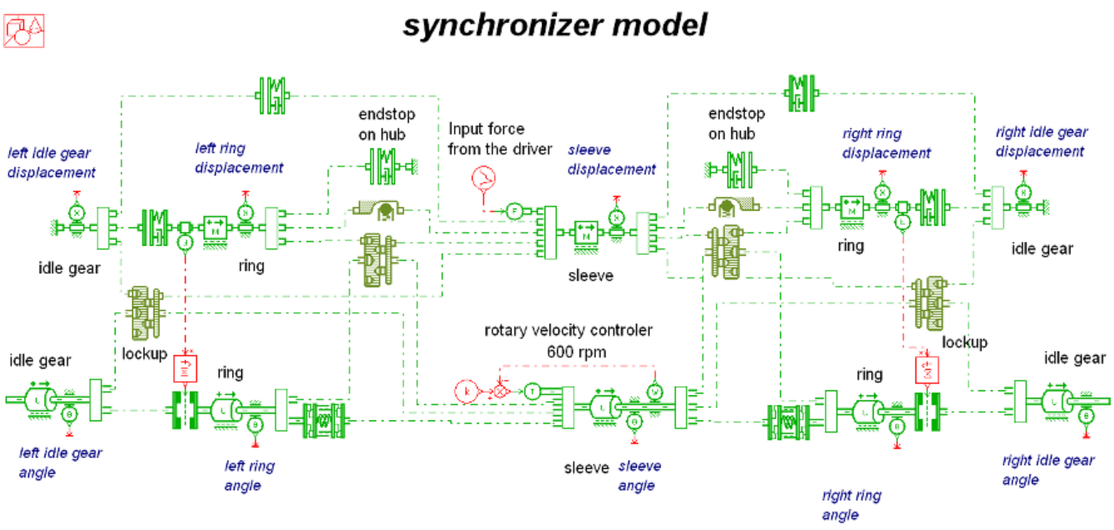

Figure 2: Model of a synchronizer in Siemens Amesim

Table 1: Dynamic parameters that effect the shifting performance

Variable	Property	Minimum Value	Maximum Value
1	Gap or clearance	0.25	0.4
2	Moment of inertia	42	60
3	Expression in terms of input x	0.003	0.006
4	Moment of inertia	0.00015	0.0003
5	Contact damping	5	20
6	Axial clearance before axial spring load	0.08	0.2
7	Axial equivalent spring stiffness	18000	25000
8	Axial clearance between dog tops when the gearbox is at the neutral (ring/idle gear frame)	0.25	0.4
9	Dog half angle	42	60
10	Applied force on fork (output at start of stage 3)	100	200
11	Constant value	500	1200
12	Sleeve speed	500	1200
13	Moment of inertia	0.12	0.17
14	Applied Load time Protocol	trapezoid	ramp
Responses	**Classification**		
1	Synchronization time		
2	Output torque		
3	Engagement time		
4	Strut detent force required		

RESULT AND DISCUSSION

The following graph shows the rotational velocity time graph of the ideal synchronizer in Amesim. The synchronization time and engagement time ranges around 0.6s and 0.2s respectively.

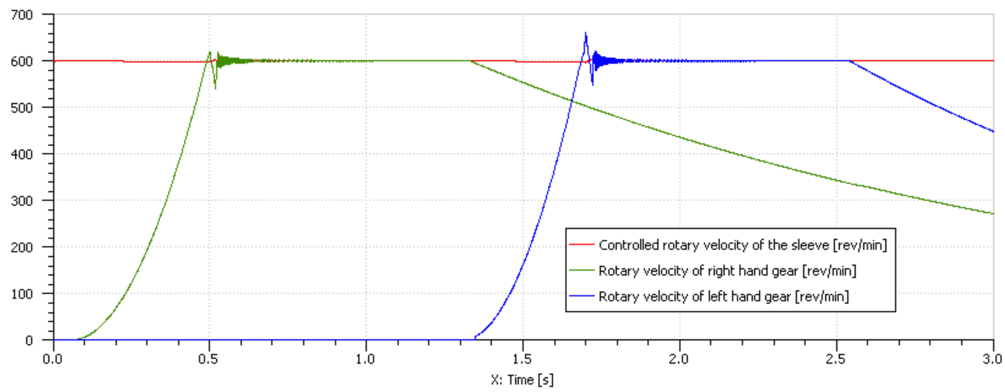

Figure 3: Ideal velocity time graph of synchronizer in Amesim

Table 2: Optimum Responses with respective parameters

Run	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10	V 11	V 12	V 13	V 14
68	0.40	42	0.0030	0.0002	5	0.08	23950	0.25	42.00	200	675	500	0.12	1
55	0.25	60	0.0060	0.0003	5	0.20	18000	0.40	48.39	100	1200	500	0.12	1
114	0.40	30	0.0047	0.0003	10	0.08	20695	0.40	42.00	200	500	1000	0.12	1
59	0.40	60	0.0060	0.0003	5	0.20	18000	0.25	60.00	145	500	1200	0.17	1

Run	R 1	R 2	R 3	R 4
68	0.29	0.39	0.150	56.5
55	0.86	0.52	0.153	38.5
114	0.39	0.21	0.100	31.0
59	0.69	0.20	0.260	24.6

The analysis of responses begin with the least synchronization time which was acquired by the run 68 of the data set, in just 0.29s. According to the run 68 the synchronizer has low moment of inertia in synchronizer rings, high clearance in the left gear, along with high spring stiffness and low axial clearance, significantly making the synchronizer's engagement and disengagement. With a torque of 52Nm, run 55 generated the maximum torque. As a result, the synchronizer experiences rapid engagement process. However, despite fast engagement, the synchronization still takes 0.86s. Some of the noticeable reasons for the high generated torque could be the low gear clearance, high moment of inertia, and low fork load, which contributed to efficient torque transfer and a faster engagement process. Run 114 provided a response with the shortest engagement time along with a relatively fast synchronization process. The engagement took a duration of just 0.098s. On the other hand, the torque generated is also comparatively low. The table shows the parameters and results of run 114. This setup consists of a high gear clearance and low moment of inertia. This influences in a faster engagement by allowing faster gear alignment. Additionally, a higher fork load led to more abrupt engagement, with the low inertia contributing to rapid rotational speed changes, resulting in a faster overall engagement process. Lastly, Figure 3 shows the graph of the detent contact force required for run 59, achieving a force of 24.76 N, the least among the data set. Table 2 shows the parameters and results of run 159. The significant parameters that are related with the run 59 are high gear clearance, high moment of inertia, low damping, and high spring stiffness. This parametric setting and output is helpful in optimizing the force efficiency and mechanical stability of the synchronizer system.

CONCLUSION

The parametric study of 14 dynamic parameters of the synchronizer across 128 simulations have been conducted using Amesim. The key influence of the parameters focus on synchronization time, output torque, engagement time and detent contact force required for the synchronization process of the manual gearbox. Primary analysis of the data leads to the determination of optimum conditions of each outcomes, minimum synchronization time in run 68, maximum output torque in run 55, minimal engagement time in run 114 and the least detent contact force in run 59. These findings show factors to consider while designing the respective parts of the synchronizer according to the targeted application. The study can be utilized to optimize and improve synchronizer performance, eventually enhancing power output and fuel efficiency.

REFERENCE

Guo, J., Zhao, Y., Chen, B., Zhang, G., Xu, Y., & Yao, J. (2023). Force Analysis of the Overconstrained Mechanisms Based on Equivalent Stiffness Considering Limb Axial Deformation. Chinese Journal of Mechanical Engineering, 36(1), 1-13.

Liu, Y. C., & Tseng, C. H. (2007). Simulation and analysis of synchronisation and engagement on manual transmission gearbox. International journal of vehicle design, 43(1-4), 200-220.

Nejad, A.F. (2019) MultiBody Dynamic Analysis of a 3D Synchronizer Model (Thesis).

Zhang, L., Peng, Y., Yang, H., & Li, S. (2022). Defect analysis and innovation design of synchronizer for clutchless automatic mechanical transmission. Chinese Journal of Mechanical Engineering, 35(1), 20.