Failure modes and optimal performance of a generic synchronizer

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The gear shifting mechanism is a crucial part of the gearbox which transmits the torque from engine to wheels with different transmission ratios. For smooth and comfortable gear changing design of the gear shifting mechanism is still a challenge for the engineers to adapt the different driving situations. In case of heavy vehicles particularly under certain circumstances optimized performance by avoiding failure modes of the gear shifting mechanism is a challenge for automotive industry. In the paper failure modes and optimal values of the system parameters are identified to contribute for this challenge. A model of multibody system of the gear shifting mechanism is developed in GT-Suite software. Failure modes are identified by performing sensitivity analysis of variables of the mechanism. Optimization routine of the GT-Suite is applied on the model by taking seven variables into account as independent variables and synchronization time as a dependent variable. Percentage changes of the variables from their initial values are calculated and analyzed. Finding of optimal values of parameters of the gear shifting mechanism is valuable contribution to design reliable and efficient transmission system for automotive industry especially for heavy vehicles.

The developed GT-Suite model of the gear shifting mechanism has three rigid bodies; sleeve, ring and gear as shown in Figure 1. The blocking teeth, spring and strut define the connection between the sleeve and the ring. There are engaging teeth and frictional cones between the ring and the gear. The system has five degrees of freedom. The sleeve has translational and rotational movement, the ring has translational and rotational movement and the gear has rotational movement. When shift force is applied on the sleeve, it translates axially and stops after a while due to the blocking teeth come in contact. The strut creates an angular difference between the blocking teeth at start and spring force is active just for 1 mm displacement before blocking teeth contact. Afterwards frictional cones slide over each other and because of frictional torque rotational speed of the gear increases while rotational speed of the sleeve remains constant throughout the gear shifting process. When speed difference approaches zeros, the sleeve moves again and completes the gear shifting process after engagement of teeth with gear.

Failure modes are identified through sensitivity analysis of seven parameters: shift force, blocker angle, spring force, indexing angle, cone angle, cone radius and cone coefficient of friction. The synchronization time is calculated as an output parameter from simulation. The sleeve axial displacement is monitored to identify the failure modes. It is identified that the synchronizer fails to perform at high shift force, low cone angle, low cone coefficient of friction, high blocker angle, low blocking teeth and high blocking angle. For example, Figure 2 shows the sleeve axial displacement vs synchronization time with varying the shift force. The mechanism fails to perform from the force higher than 2000 N because the sleeve translates almost continuously without giving sufficient time for cones sliding to decrease the speed difference.

After identifying parameters bounds at which failure modes can happen, values of the parameters are sought out at which the gear shifting mechanism can perform optimally. The optimization routine of GT-Suite with genetic algorithm is applied with default settings to search optimal values of the parameters to minimize the synchronization time. Seven parameters are taken as independent variables as shown in Table 1. For example, Figure 3 shows three areas of points crowd that means at these areas cone coefficient of friction has optimal value. More crowded area of friction coefficient is selected which is at about 0.27. Optimal values with percentage change are given in Table 1.

In this paper, the lowest/highest bound of the seven parameters are identified to avoid the failure modes and the values that minimize the synchronization time are found. Percentage improvements of the parameters from initial values to optimal values are noticeable. But the gear shifting processes are not as simple as studied here. The process can be affected by driveline vibration, road inclination as presented in [1], temperature variations etc. Even the gear mechanism being a part of gearbox is not as simple as presented here. The gear shifting mechanism can also be studied further with other parts of the gearbox for example with bearings and gears etc.

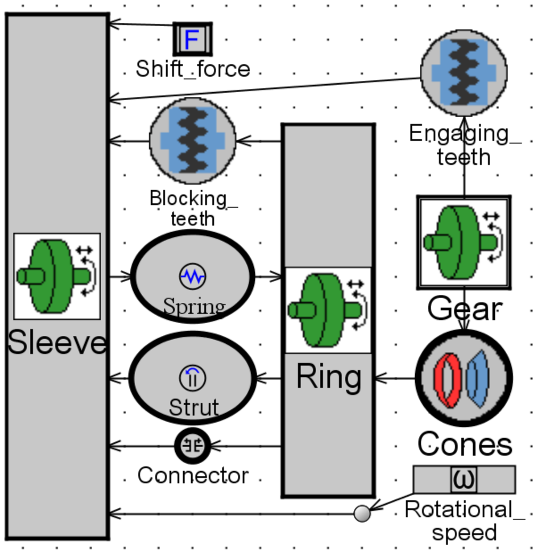

Figure 1: Gear shifting mechanism in GT-Suite.

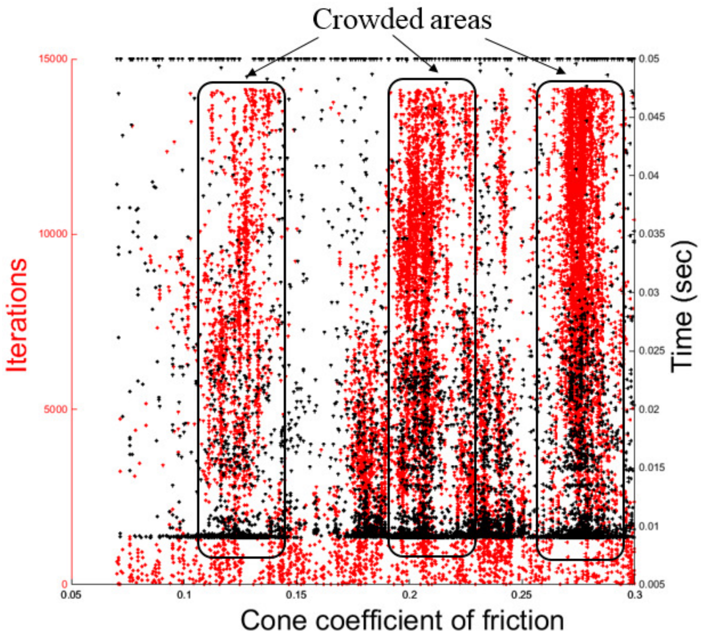

Figure 3: Cone coefficient of friction with iterations and time.

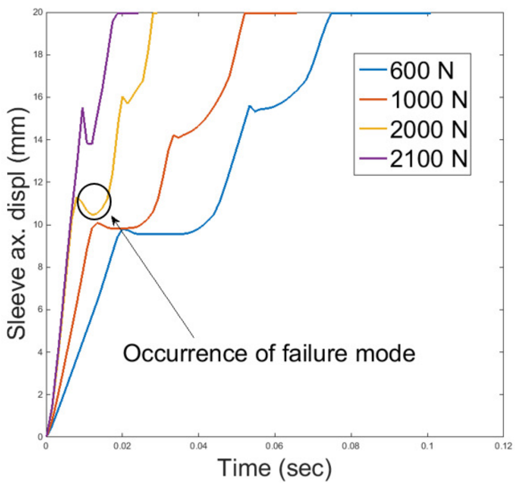

Figure 2: Sleeve axial displacement with varying shift force.

<table>
<tr><td colspan="2">Dependent variable</td><td></td><td>Independent variables</td><td>Initial values</td><td>Variables bounds</td><td>Optimized average values</td><td>Percentage change</td></tr>
<tr><td colspan="2" rowspan="2">Synchronization time (sec)</td><td>1</td><td>Shift force (N)</td><td>1000</td><td>300-2500</td><td>2500</td><td>150</td></tr>
<tr><td>2</td><td>Cone coefficient of friction</td><td>0.17</td><td>0.07-0.3</td><td>0.27</td><td>58.8</td></tr>
<tr><td>Initial value</td><td>Optimized value</td><td>3</td><td>Cone angle (deg)</td><td>7</td><td>5-15</td><td>5</td><td>28.6</td></tr>
<tr><td>0.03</td><td>0.01</td><td>4</td><td>Engaging teeth radius (mm)</td><td>65</td><td>50-80</td><td>57</td><td>12.3</td></tr>
<tr><td colspan="2">Percentage change</td><td>5</td><td>Blocking teeth radius (mm)</td><td>65</td><td>50-80</td><td>80</td><td>23</td></tr>
<tr><td colspan="2" rowspan="2">66.66</td><td>6</td><td>Ring moment of inertia (kgm^2)</td><td>0.004</td><td>0.001-0.05</td><td>0.0075</td><td>87.5</td></tr>
<tr><td>7</td><td>Gear moment of inertia (kgm^2)</td><td>0.05</td><td>0.04-0.1</td><td>0.04</td><td>20</td></tr>
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Table 1: Variables with initial values and optimized values.

References

[1] M. Irfan, V. Berbyuk and H. Johansson, "*Constrained Lagrangian Formulation for* modelling and analysis of transmission synchronizers," 2015:05 Department of Applied Mechanics Chalmers University of Technology, Gothenburg, 2015.