Handling Evaluation of Tractor-semitrailer with Split Fifth Wheel Coupling Undergoing an ISO Double Lane Change Manoeuvre

A. Jogi¹, S. Chandramohan¹, S. Dash²

¹ Department of Mechanical Engineering
Indian Institute of Technology Madras
Chennai, India -600036
ajithjogi@gmail.com, sujatha@iitm.ac.in

² Department of Mechanical Engineering
National Institute of Technology Tiruchirappalli
Trichy, India -620015
sabyadash21@gmail.com

ABSTRACT

Tractor-semitrailers face the issue of off-tracking which restricts their movement through congested areas. One of the innovative and passive methods to reduce off-tracking in tractor-semitrailers is to implement a Split fifth wheel coupling (SFWC). Studies show that off-tracking is reduced by up to 21% for a circular turning manoeuvre. The handling performance of the tractor-semitrailer with SFWC is not evaluated yet and hence needs to be addressed. In the present work, in order to assess the handling performance of the vehicle with SFWC, simulations are carried out for ISO double lane change manoeuvre at various speeds. The results are compared with those of the Conventional fifth wheel coupling (CFCW) model to understand the relative performance of the tractor-semitrailer with SFWC. The results show that the performance of tractor-semitrailers with SFWC is on par with that of vehicles with CFCW at lower speeds; in fact, for speeds below 40 kmph, the lateral acceleration experienced by the semitrailer of SFWC vehicle is less compared to that of CFCW vehicle. However, it becomes a little unstable at higher speeds. With the development of stability control systems like Electronic stability control (ESC), optimized for tractor-semitrailers with SFWC, their performance would improve.

Keywords: Split fifth wheel coupling, Off-tracking, Hitch, Tractor-Semitrailer, DLC, Handling

1. INTRODUCTION

Tractor-semitrailers are articulated freight carrying vehicles, where a portion of the trailer's load is supported by the tractor. Usually, these are lengthy vehicles making them difficult to manoeuvre in congested roads, since the space required to take the turn increases with wheelbase. Off-tracking is a metric to measure this turning space, which is defined as the radial distance between the trajectory of the front and rearmost axles of a vehicle during the turning manoeuvre. Many researchers, including Jindra [1], Pretty [2] and Choi et al. [3] have worked on the modelling of off-tracking. Steering the semitrailer axle is one of the effective methods for reduction of off-tracking; however, it includes a complex system to control the steering, which makes it expensive. Jogi and Chandramohan [4] have developed a new hitch mechanism, termed Split fifth wheel coupling (SFWC) which reduces the maximum off-tracking by a significant margin. SFWC is a passive mechanism without the inclusion of complex systems.

It is necessary to evaluate the handling performance of the tractor-semitrailer with SFWC to ensure its safe operation. Double lane change (DLC) manoeuvre is one of the handling evaluation methods, wherein the vehicle swiftly changes its lane and comes back to its original lane to avoid an obstacle. There are various kinds of DLC specifications which have been compared with each other by Peng and Yang [5]. ISO DLC is one of the standards for such tests. ADAMS /Car tool is capable of performing the simulations of closed-loop ISO DLC test and provides good results [6].

1.1. SFWC

The Conventional fifth wheel coupling (CFWC) consists of a turntable fixed to the chassis of the tractor. It receives the kingpin of the semitrailer, forming a joint which serves not only as an articulation point, but also as the point of vertical load transfer from the semitrailer to the tractor. Figure 1 (a) shows the conceptual model of the tractor-semitrailer with CFWC. On the other hand, SFWC being a novel off-racking reduction mechanism, the articulation point and the point of vertical load transfer have been separated by a certain distance. It consists of two sub-units: cylindrical joint and roller mechanism, as shown in Figure 1 (b). The former takes care of articulation, whereas the latter allows the vertical load transfer from the semitrailer to the tractor even when the vehicle is articulating. Studies have shown that the SFWC, when equipped on the conventional tractor-semitrailer, reduces maximum off-racking by up to 21% for a circular manoeuvre [4]. When analysed for 90° and 180° turning manoeuvre, it was found to reduce the maximum off-racking by up to 13.9% and 14.7% respectively [7].

Figure 1. Conceptual model of the tractor-semitrailer with (a) CFWC (b) SFWC (Courtesy: Jogi and Chandramohan [7]).

2. METHODOLOGY

In the present work, a multi-body virtual prototype is built using the ADAMS Car tool. Initially, the CFWC model is built as per the specifications of AASHTO Standard Interstate Tractor-Trailer WB-62, specifications of which are mentioned in Appendix 1. Using the template builder option, CFWC model is modified into SFWC, by adding a roller mechanism and curved track. The kingpin offset chosen for the SFWC model is 812.8 mm. To evaluate the handling performance of the vehicle with SFWC, it is simulated for closed-loop ISO double lane change (DLC) manoeuvre, the specifications of which are mentioned in Figure 2. Five speeds are chosen for the study: 20 kmph to 60 kmph with an interval of 10 kmph.

Figure 2. Specifications of ISO DLC course for heavy vehicles (Courtesy: MSC Software Corporation [8])

As shown in Figure 2, the actual length of the ISO DLC course is 170 m; however, to study the behaviour of the vehicle after finishing the course, the vehicle is run for an additional distance of about 130 m. The turn direction is chosen to be right for all simulation runs. The default value for the caster, camber and toe angles are chosen as 0° . Gear position is selected as suggested by the tool for the engine speed to be in the range between stall speed and max revolutions per minute limit. The default 2D flat road and default controller are used for all simulation runs. The simulation data are used to plot the trajectory, yaw rate response, lateral acceleration response and articulation angle response of both the vehicle models. To understand the relative performance of the tractor-semitrailer with SFWC, the results of both models are compared with each other and useful conclusions are drawn.

3. RESULTS AND DISCUSSION

The comparison of trajectories of the two vehicles at different velocities with respect to the target path is carried out. This gives insight into the ability of the vehicle to follow the ISO DLC path at various speeds. Figure 3 shows the trajectory of the tractor and semitrailer units of both SFWC and CFWC models at speeds varying from 20 kmph to 60 kmph with a step size of 10 kmph. One can observe that both the models trace the ISO double lane change path pretty well. The path traced by the units of tractor-semitrailer with SFWC matches that of the respective units of the CFWC model for speeds below 40 kmph. At 50 kmph speed, both vehicles show some instability after exiting the last turn of the DLC course. At 60 kmph the SFWC model tends to oscillate more than the CFWC model; however, both models complete the test without the lift-off of any of their wheels. Since the behaviour of both vehicles is similar at speeds below 40 kmph, the trajectory of the tractor unit of SFWC model exactly matches that of CFWC. However, at 40 kmph speed one can observe that the semitrailer unit of SFWC traces comparatively an inner path. Since its path is slightly closer to that of its tractor, one can understand that the off-tracking posed by SFWC model is less.

Figure 3. Trajectory of the tractor-semitrailer with SFWC and CFWC at various speeds

Figure 4 shows the yaw rate response of the vehicles at different speeds. The yaw rate response of both SFWC and CFWC models match each other at 20 kmph, however, at 30 kmph there is a noticeable difference during the last turn of the DLC course. This difference is even more pronounced at 40 kmph, the yaw rate of the SFWC model being higher during the turns. The trend of the yaw rate response is similar for speeds 20, 30 and 40 kmph. At 50 and 60 kmph speeds, the trend is quite different from the rest because of the instabilities arising due to the high-speed cornering.

Figure 4. Yaw rate response of the tractor-semitrailer with SFWC and CFWC at various speeds

The study of the lateral acceleration experienced by the vehicle plays an important role. Figure 5 shows the lateral acceleration response of the vehicle tractor and semitrailer at different speeds. There is a noise in the lateral acceleration data during the beginning of the simulation run and can be ignored. Again, the trend followed by the lateral acceleration response at speeds 50 and 60 kmph is different from that of 20, 30 and 40 kmph for both the vehicle models. One can observe that the peak lateral accelerations experienced by the vehicle units occur during the turns. Also, the semitrailer units experience less lateral acceleration when compared to their respective tractors, due to the fact that, their path is comparatively a smoothened curve, which is evident from the trajectory plots. Interestingly, the lateral acceleration experienced by the semitrailer of SFWC vehicle is less when compared to that of CFWC vehicle for speeds below 40 kmph. Due to high speeds, the vehicles are not able to take sharp turns, which is evident from the yaw rate response for 50 and 60 kmph. Hence, corresponding lateral acceleration values also decrease when compared to those of 40 kmph. The actual curves for lateral acceleration for both units of SFWC at speeds 50 and 60 kmph contain a large amount of noise and hence are smoothened (smoothing parameter $p = 0.999$) for better representation. The actual plots and curve-fitting data can be found in Appendix 2.

Figure 5. Lateral acceleration response of the tractor-semitrailer with SFWC and CFWC at various speeds

Figure 6 shows the articulation angles of the tractor and semitrailer units of both SFWC and CFWC models at speeds varying from 20 kmph to 60 kmph at intervals of 10 kmph. Again, the trend of the articulation angle curve for speeds between 20 and 40 kmph are similar to each other and different from the rest of the speeds. The articulation angle of SFWC vehicle is comparatively higher at all the speeds, owing to the fact that the effective wheelbase of the semitrailer of the SFWC vehicle is smaller, the overall length being the same.

Figure 6. Articulation angle curves of the tractor-semitrailer with SFWC and CFWC at various speeds

4. SUMMARY AND CONCLUSION

To study the handling characteristics of the tractor-semitrailer with SFWC in comparison with the conventional vehicle, the DLC test is carried out, which is an obstacle avoidance manoeuvre. The virtual prototypes of both the vehicle types have been subjected to ISO DLC using the ADAMS/ Car tool at different speeds ranging from 20 kmph to 60 kmph with a step size of 10 kmph. The SFWC model traces the target path pretty well at lower speeds; however, it is a little unstable at higher speeds when compared to the CFWC model. The behaviour of both vehicles changes significantly between from 40 to 50 kmph. The lateral acceleration response explains that the DLC is a very dynamic manoeuvre and can generate rapid rates of change of lateral acceleration. Interestingly, for speeds below 40 kmph, the lateral acceleration experienced by the semitrailer of SFWC vehicle is less compared to that of CFWC vehicle. One should note that the DLC manoeuvre is highly dependent on the driver's steering input. The default driver model present in ADAMS/ Car tool is optimized for the tractor-semitrailer with CFWC. Hence, the actual steering input to be given to SFWC vehicles may vary. In the present study, the performance of the tractor-semitrailer with SFWC is on par with that of CFWC at speeds below 50 kmph. The vehicle's inability to trace the ISO DLC path is more pronounced at higher speeds. With the development of stability control systems like ESC, optimized for tractor-semitrailers with SFWC, their performance would improve.

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APPENDIX 1

Specifications of reference tractor-semitrailer: Interstate Tractor-Trailer WB-62

Figure A1. Specifications of reference tractor-semitrailer Interstate Tractor-Trailer WB-62

APPENDIX 2

The lateral acceleration response (with noise) and curve-fitting data

Figure A2. Lateral acceleration response of the tractor-semitrailer with SFWC and CFWC at 50 and 60 kmph speed without smoothing of the curves

Curve fitting data for SFWC lateral acceleration response:

- Smoothing spline: $f(x)$ = piecewise polynomial computed from p
- Smoothing parameter: $p = 0.999$

Table A2. Goodness parameters of the fit

	SFWC Tractor	SFWC Trailer
SSE	1.907	0.871
R-square	0.7993	0.8946
Adjusted R-square	0.7769	0.8828
RMSE	0.04296	0.02903