

Kinematic Analysis of Tractor-Semitrailer with Split Fifth Wheel Coupling During Low Speed Turning Maneuvers

Ajith Jogi and Sujatha Chandramohan
Indian Institute of Technology - Madras

ABSTRACT

Over the years, commercial vehicles, especially tractor-semitrailer combinations have become larger and longer. With the increasing demand for their accessibility in remote locations, these vehicles face the problem of off-tracking, which is the ensuing difference in path radii between the front and rear axles of a vehicle as it maneuvers a turn. Apart from steering the rear axle of the semitrailer, one of the feasible ways of mitigating off-tracking is to shift the fifth wheel coupling rearwards. However, this is limited by the distribution of the semitrailer's load between the two axles of the tractor; any rearward shift of the fifth wheel coupling results in the reduction of the total static load on the tractor's front axle and hence available traction. This may in turn lead to directional instability of the vehicle. In the present work, a new model of the fifth wheel coupling is proposed which the authors call Split fifth wheel coupling (SFWC). Here, unlike the Conventional fifth wheel coupling (CFWC), the point of load transfer from the semitrailer to the tractor and the point of articulation are separated by a certain distance. A comparative study of the kinematic analysis for the vehicle combination with CFWC and SFWC is discussed in this paper. It is observed that the latter noticeably reduces off-tracking when compared to the vehicle with CFWC for a tractor-semitrailer combination of similar dimensions.

CITATION: Jogi, A. and Chandramohan, S., "Kinematic Analysis of Tractor-Semitrailer with Split Fifth Wheel Coupling During Low Speed Turning Maneuvers," *SAE Int. J. Commer. Veh.* 10(2):2017, doi:10.4271/2017-01-1554.

INTRODUCTION

Freight transportation plays a major role in the economy of a country. It is a proven fact that a good rail network is always economical when compared to other means of transportation on land, especially for bulk transportation. But when it comes to the case of door-to-door shipment, commercial road vehicles, in particular tractor-semitrailers are the most viable option. In developed countries like USA, Japan and Netherlands, the road networks are well established; well-designed roads always aid in the smooth operation of these vehicles. In recent years, civil design engineers have been considering the turning profile [1] of various vehicle combinations while designing highway intersections, roundabouts and parking lots. This is due to the fact that improper designs could cause accidents; large off-tracking of vehicles could be one of the reasons. Off-tracking becomes very significant when large vehicles undertake a turning maneuver.

The analysis of the movement and loci of various parts of a vehicle when it negotiates a curve is collectively termed as swept path analysis and off-tracking is one of the parameters most engineers focus on. A lot of study has been carried out to formulate mathematical expression for off-tracking [2]. Also there is plenty of literature in modeling the off-tracking [3, 4, 5, 6] and to reduce it. Though rear axle steering [7] and addition of more articulation joints are well accepted solutions, they are associated with certain drawbacks.

PROPOSED APPROACH

Besides steering the semitrailer rear axle and increasing articulation joints, one could think of shifting the fifth wheel coupling behind the tractor's rear axle, though stability issues have to be looked into [8]. In order to maintain proper traction between wheels and ground, load distribution between the tractor's axles has to be taken care of, thereby imposing a constraint of load transfer point being positioned in front of the tractor's rear axle. Hence there is a need for a mechanism to reduce off-tracking without affecting the load distribution among the axles. This paper presents a unique way of fulfilling these constraints and is discussed in the following sections.

SFWC

The basic idea behind SFWC is splitting the functions of a fifth wheel coupling. The functions of a CFWC are:

- Load transfer from semitrailer to tractor's chassis
- Transmission of longitudinal and lateral forces (tractive pull and articulation)
- Imparting articulation, roll and pitch limits (allowing the independent motion of semitrailer without transmitting the direct force to the tractor)

Figures 1a and 1b show the 3D conceptual model of the tractor-semitrailer with SFWC. The articulation is achieved by a cylindrical joint with 2 degrees of freedom (DOF): rotation about z-axis, i.e., yaw motion and translational motion along positive z-axis, i.e., bounce. The cylindrical joint consists of two parts-kingpin, which is rigidly mounted on the chassis of the semitrailer and the cylindrical mating part, which is mounted on the chassis of the tractor. The cylindrical joint only offers reaction forces in the x-y plane of the vehicle and all vertical forces are taken care of by the roller mechanism shown. The weight of the semitrailer is distributed between its axle and the roller mechanism according to their respective distances from the semitrailer's center of gravity (CG). The need for a roller mechanism is to enable load transfer even when the vehicle is articulating. The roller rolls on the track provided on the tractor's chassis during articulation. In order to prevent the roller from rolling out of the tractor's chassis during a sharp turn, the maximum articulation angle is limited by the width of the tractor's chassis and the distance between the axis of the cylindrical joint and the roller contact point. The number of such rollers can be increased to widen the limits of the articulation angle.

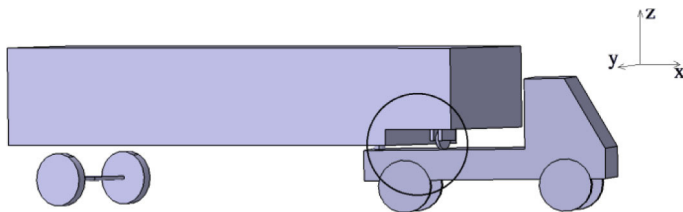


Figure 1a. Conceptual 3D model of the tractor-semitrailer with SFWC

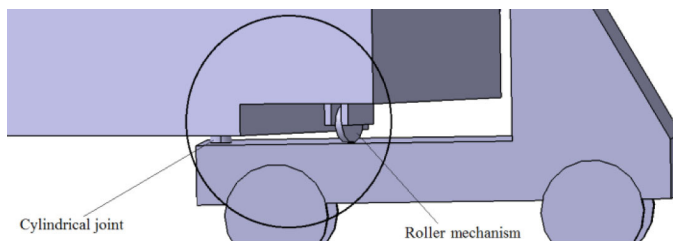


Figure 1b. Zoomed view of the SFWC showing cylindrical joint and roller mechanism

When the tractor and semitrailer pass over a vertically uneven road surface, there is a difference in pitch angles between the tractor and the semitrailer. The roller mechanism stays in contact with the track on the tractor's chassis and this movement has to be accommodated by the cylindrical joint. A simple cylindrical joint with the cylindrical mating part which is rigidly fixed to the chassis of the semitrailer, would not allow any relative motion between these two units in pitch and roll direction. Hence the cylindrical mating part is provided with two additional DOF: rotation about local x and y axes, with appropriate limits as shown in Figure 1c.

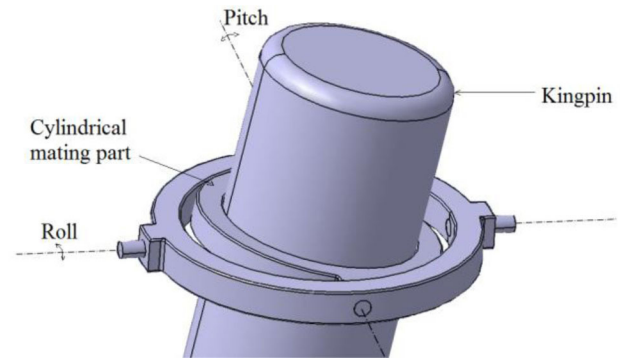


Figure 1c. Conceptual representation of cylindrical joint with two supplementary rotational DOFs

Need for Kinematic Analysis

Kinematic analysis is a primary step to analyze the steering geometry of a ground vehicle. Once it is found by kinematic analysis that there is significant advantage in terms of reduced off-tracking by implementing SFWC model, further study can be done considering the dynamic effects. In the kinematic analysis, one can find out the trajectory of different points on the vehicle and the zero-speed off-tracking, wherein the mass of the vehicle and the forces acting on it are not considered.

METHODOLOGY

The kinematic analysis of the tractor-semitrailer with the proposed concept of SFWC is performed and the results are compared with those of the CFWC model, assuming that the overall length of the vehicle remains the same, as represented in Figure 2.

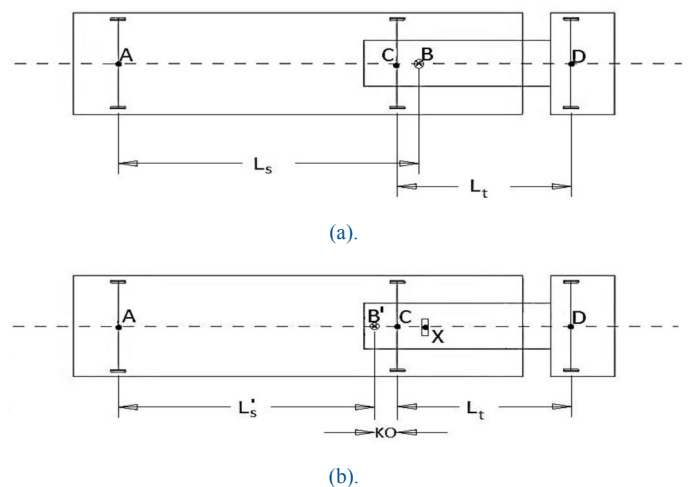


Figure 2. Geometrical representation of tractor-semitrailer (top view) with (a) CFWC and (b) SFWC

