Kinematic study of the articulated trucks operating layout of turn for articulated vehicles

Y P Sofronov¹, Y P Stoyanova², N E Kopralev¹ and G D Todorov¹

¹Faculty of Industrial Technology, Laboratory „CAD/CAM/CAE in Industry”, Technical University of Sofia, Sofia, Bulgaria,
²Faculty of Industrial Technology, Department “Theory of mechanisms and machines” University of Sofia, Sofia, Bulgaria,

E-mails: ysofronov@tu-sofia.bg, yast@tu-sofia.com, nkopralev@3clab.com, gdt@tu-sofia.bg

Abstract. In this article, a kinematic analysis of articulated forklift truck turning has been made. Articulated steering systems separate the vehicle into a front and back sections, with a pivot (articulated) point directly joining them in the middle. This allows them to be rotated one compared to the other. In most cases, the turning of the vehicle is accomplished when force is applied to front section, via hydraulic cylinders thus creating torque in the articulated joint or directly applying torque via electric/ hydraulic motor. This allows such vehicles to have greater manoeuvrability and flexibility compared to the conventional forklift trucks making them preferable in the modern warehouses, which allows reduction in its isle width and as such increase in the its overall capacity which is of utmost importance. The minimum width of aisle and junction allowing articulated forklift truck with set dimensions to properly pass are been evaluated.

1. Introduction

According to the dictionary, articulated means jointed or segmented. This definition agrees well with the common impression of an articulated vehicle. Such a vehicle consists of two or more body or frame units jointed together. These units or sections should be an integral part of the vehicle. The joints may have one, two or three degrees of freedom (yaw, pitch and roll) [1, 2].

In comparison to equipment with articulated frame steering, equipment with single-axle steering and identical undercarriage geometry has the significant disadvantage that it is considerably less flexible and maneuverable and thus possesses lower performance capability [3].

With the articulated forklift, the operator can see the load being handled well than a reach truck operator can see his load. This is because here the operator will pick and place loads at a 90° angle to the machine. Visibility from the side is unobstructed when compared to a reach truck operator trying to see through the mast and reach mechanism. In fact, reach trucks operators can often be seen leaning outside of the operator’s compartment to get a better view of the forks or the load being handled [4].
Outside of the aisle, the operator’s visibility can be improved in much the same way as it is in the aisle by picking and placing loads at an angle instead of straight ahead, whenever possible. The reach truck operator is always working from a position behind the mast and reach mechanism where visibility is obstructed [4].

Another big advantage over reach trucks, depending on the application, is that the articulated truck can be configured to load and unload trailers. This trailer to rack capability eliminates the expense of additional equipment and personnel needed to operate that equipment [4].

A reach truck requires staging areas for temporary storage between the dock and the rack. Because the articulated truck can work trailer to rack and back, staging areas are not required and additional pallet positions are created. Reach trucks are rarely able to load and unload trailers because of their small front wheels and low ground clearance [4].

Aim of this study is determine what should be the narrowest aisle in which the articulated forklift, with defined geometry, could operate. Usually in technical specification this is presented as steady state geometry without taking into account envelop of turning. Geometric modeling and calculations [5] provide insight into the details of how products interact with the environment, and allow new products to be evaluated in the computer, even before prototypes have been built. This is driven by the Virtual Prototyping (VP) ability to cut down developmental costs by minimizing physical testing which can result in considerably reduced design cycle time and design costs [6].

2. Exanimated model
The simplified geometric model of an existing articulated forklift truck in straight position is shown in figure 2. The geometric parameters (in meters) of the devised model are shown on Table 1.

Process of moving of such vehicles consists of two independent variables [7] and nonholonomic relations should be used to present it. The first one is the movement of the front side where traction motors are installed and second one is steering angle produced by operator with steering wheel. Steering wheel with transfer mechanisms produces torque around pivot point.
Combinations of these variables produce trajectories which could be calculated using MS Excel spreadsheet [8]. The rear of the articulated truck is a trailing link attached to the articulated joint of the vehicle and has two degrees of freedom: it could roll in the direction of its centre-line, while also rotating about the centre of the rear axle group. Determining the trajectories [9] traced out by the border points on the vehicle is based on being able to calculate how the position of the centre of the rear axle varied as the articulated joint moves. Where the front of the forklift travelled in a straight line, the centre of the rear axle is following a curve. This type of trailing-link motion is modelled by a succession of small increments of the movement of the whole machine.

The analysis used here did not take into account the dynamic effects and finite displacements of the truck’s reference points were used to calculate each new position respectively.

3. Analytical methodology

Modelling of the trajectory was done using following methods.

Rotation

This subroutine allows a point to be rotated about another point and makes use of trigonometric principles in a straightforward way.
Figure 3. Defined pallet and chassis by border points.

Trail
This subroutine has been written to calculate the new position of the forklift’s rear end when the front is moved through a distance in a straight line. The underlying principle is that, for an infinitesimal displacement of the head in any direction, the new position of the rear will lie on a straight line that joins the original position of itself to the new position of the front.

Rotation by Radius
For the articulated truck—or indeed for any non-articulated, front-axle-steered vehicle—there will be a specific turning radius associated with any particular position of the steering wheel (or amount of steering). The turning centre (or centre of rotation) lies on the centre-line of the rear. The turning centre also lies on the axis of each of the steered front wheels.

Subroutine Rotation by Radius calculates the new position of a reference point that is rotated about a centre with a given radius and through a given trajectory distance. It also calculates the coordinates of the centre of rotation and the direction in which the trajectory is pointing at the end of the travel.

Steer
Subroutine Steer builds on the functionality of subroutine RotationByRadius, which it calls, and allows two inverse turning radii to be specified: one at the beginning and the other at the end of the travel. Within the subroutine it is assumed that the inverse turning radius varies linearly with the distance travelled: this is a fair approximation if the steering wheel is being turned at a steady rate with respect to distance travelled.

SteerAndTrail
Subroutine SteerAndTrail, like subroutine Steer, builds on the functionality of subroutine RotationByRadius, which it calls, and allows beginning and ending inverse turning radii to be specified. However, SteerAndTrail calculates the new position and direction of the rear at the end of the movement by using the functionality of Trailing, which it also calls.
4. Results from performed analysis
For the examined problem here, a spreadsheet was used to determine the minimum isle width that would be required for an articulated truck to properly and safely operate in. The situation that is observed is the one that is most intriguing for the warehouse planner – a 90° corner for the forklift to steer from one isle to another perpendicular to it.

Using the built-in function MAX the X and Y coordinates of all the points of the articulated truck including the standard pallet with dimensions 1200x1000mm were traced in time of the truck’s steering action, thus creating contours whose envelop can be used to determine the minimum isle width.

Diagram showing the paths envelop of the truck in proper scale is shown on figure 4. The calculated dimensions for the isle’s intercrossing are shown in table 2.

| Table 2. Coordinates of the calculated isle cross-section |
|----------------------------------|-----|-----|
| Point               | X   | Y   |
| Corner              | 1.3 | -6  |
| Right most          | 1.3 | 0   |
| Bottom most         | 10  | 0   |
| Left most           | -0.952 | -6 |
| Top most            | -0.952 | 2.379 |
| Incoming Aisle      | 10  | 2.379 |
| Outgoing Aisle      | 2.252 | -  |
|                     | 2.379 | -  |

Figure 4. Generated trajectories of the reference points

5. Conclusion
This paper demonstrates the use of a spreadsheet application to solve engineering problems relating to the turning or steering of articulated forklift trucks. Analytical methodology is developed to study the turn envelop using steering kinematics for articulated forklift truck and the width of narrowest isle in defined dimensions of the truck have been calculated. It is found that by adjusting the articulated joint position, the wheelbase and the distance between wheel groups contact centres, the distance between the isles in a warehouse can be significantly decreased – increasing the warehouse capacity and reducing the cost for pallet for the storage. The developed methodology could be used to optimize geometric parameters for vehicles with similar kind of steering kinematics and applications.
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