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THE SELECTED PROBLEMS OF COMPUTER AIDED DESIGN OF PRT (PERSONAL RAPID TRANSIT) VEHICLES

Abstract: The paper concerns the Dynamics of PRT vehicles. A brief characterization of PRT transport has been presented indicating the problems of vehicle dynamics. Also the structure of a bogie system has been outlined based on the invention patent filed in the Patent Office, which was developed by the authors of this paper. Additionally, a three-dimensional simulation model of a PRT (Personal Rapid Transit) vehicle has been presented. The model was prepared in Adams environment which is typically used for simulation of Multibody Systems. The modeled vehicle is relatively simple while preserving the mass and inertial parameters of a CAD model, which had been developed in Catia V5 system before. The model accounts for problems of contact, friction and slip, which accompany the contact of wheels with the track and the rolls leading a vehicle along a track. Substantial research has been conducted in order to analyze the sensitivity of selected dynamic features to various parameter changes.
Keywords: Personal Rapid Transit, dynamics of PRT, modeling and simulation

1. INTRODUCTION

PRT transport system is one of automated transport forms called AGT (Automated Guideway Transit – automatic transport without a driver) [1], which combines the features of both personal and mass city transport of a ‘point-to-point’ or ‘door-to-door’ type consisting of small vehicles (e.g. four-passenger ones), remotely controlled and moving along a light infrastructure – typically an elevated track. The ‘point-to-point’ feature means that the journey is made from the initial to the final stop without any intermediate ones. This intelligent system chooses an optional route by itself, which, depending on the volume of traffic in the network of routes, ensures that the criterium of minimum travel time is met. The Faculty of Transport at the Warsaw University of Technology is currently doing research on the study of the dynamics of vehicle movement. Different concepts of the running system construction are being analyzed, including the one presented in this paper.

1.1. Problems of the dynamics of PRT vehicles

One of the most vital problems in PRT systems is ensuring such a steering method for PRT vehicles at junctions that it does not necessitate the decrease of velocity and guarantees a swift change of direction. To meet these conditions it seems necessary to relocate the switch, which traditionally is attached to the track guide, into the vehicle itself. This solution does not require the construction of any movable elements on the track guide. The track therefore is always ready for another vehicle and it is not necessary to wait for the change of its configuration after a vehicle changing its direction has passed.

The compliance with the above mentioned requirements is strictly connected with the shifts of the elements of bogie system of a vehicle during its journey and a ride without a significant decrease of velocity at junctions and transition curves. Moreover, the construction of the bogie system must facilitate ride on tracks with small radius curves. Such demanding requirements and conditions of work/ride make it difficult to construct a vehicle, which conforms to comfort and safety standards of the passengers, including maximum acceleration and the velocity of acceleration progress.

2. DESCRIPTION OF CONSTRUCTION SOLUTIONS

Due to simulation studies of various construction solutions of a PRT vehicle bogie, there emerged a solution in which the running system consists of a single-axel bogie and a middle guide rail. Apart from this, lateral guide wheels are used in passive switches. The direction of movement through a junction is realized by a special mechanism included in the running system of the vehicle. Additionally, the currently modeled PRT vehicle is suspended under a track and the vehicle’s drive is possible due to linear motor.

2.1. Description of the patented solution

The schema of the solution is presented in Figure 1. The vehicle consists of a cabin 1 suspended through a device for shock absorption 2 to the bogie 3 moving along a one-unit guide way 4, in which there is a system of immobile guide rails 5, 6, 7. The running system of the vehicle contains three-points guides A, B, C, with the point B situated at the distance L from the geometric line joining A and C in the direction of the OX axis of the presented coordinate system. The value of L is constant and ranges from 0.1 m to 5.0 m depending on the geometric characteristics of a vehicle cabin. The interdependent position of points A, B, C, which do not move in relation to each other, is dependent on the geometry of running system 3.

In order to describe the functioning of running system, local coordinates system LCS have been introduced as presented in Figure 1. They move together with the running system whose axis X points to the direction of movement, and axis Y is vertical. The construction of points A, B, C is symmetric to the XY plane. The presented invention has been developed by the authors of this paper and filed in the Patent Office (number P383748).

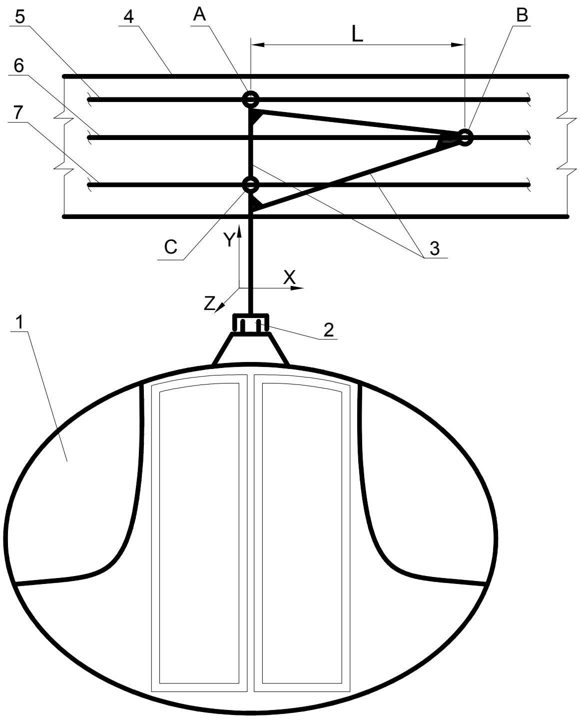

Figure 1. The schema of a construction solution of a bogie system and the schema of a PRT cabin attachment to the running system (according to patent nr P383748 Choromański, Dobrzyński, Kowara)

Based on the schema presented in Figure 1, a simple dynamic model has been developed accounting for a rigid track. This model is presented in Figure 2.

3. NOMINAL MODEL

3.1. Model of a vehicle

The model of the running system incorporates the idea of a single-axel bogie and the fact that the vehicle rides on a single track line positioned in the middle and that there is a bottom track line controlling the roll angle of the vehicle. The main support wheels are positioned in point A, where additionally lateral guide wheels are provided. Point B accounts for the steering and point C controls the roll angle. The nominal construction model has been devised as presented in Figure 1. The position and orientation of the model with respect to the inertial coordinate system OXYZ, connected with the base, is as follows:

- axis X is directed along the guide way
- axis Z is directed upwards
- axis Y complements the system of axes in case of right-handed coordinate system

The assumed orientation is going to be preserved while constructing the model in MBS systems.

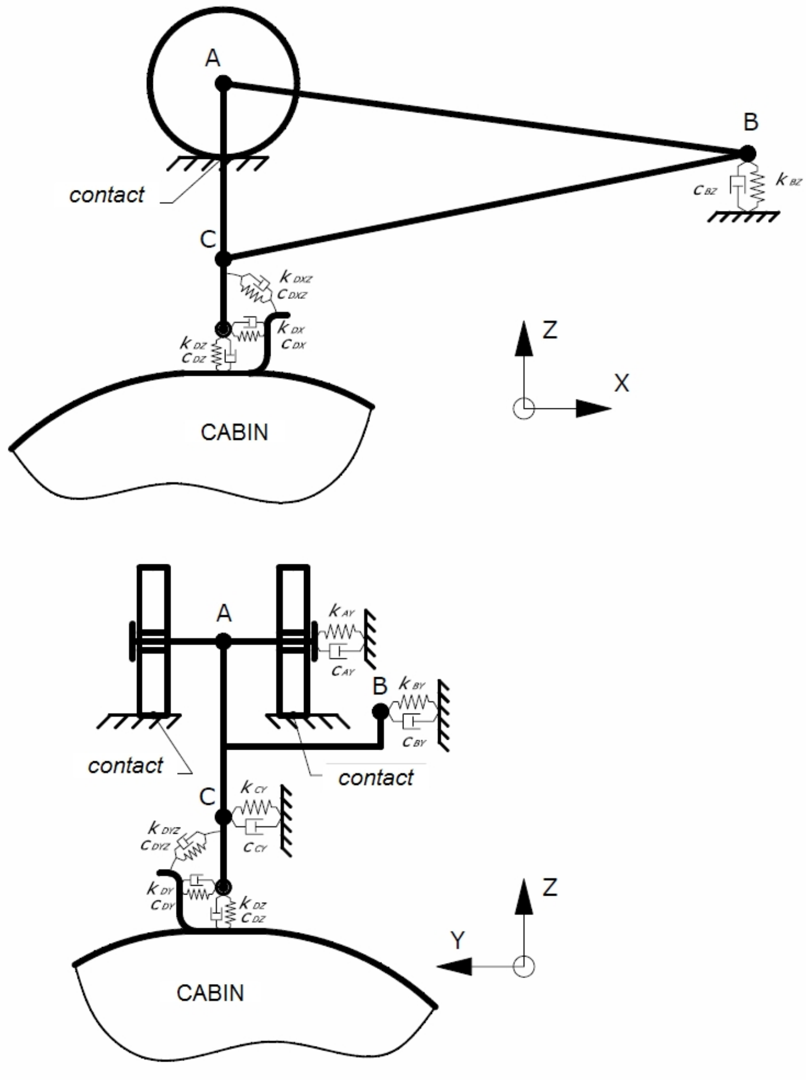

Figure 2. Nominal model of a PRT vehicle with rigid track

Based on the model presented in Figure 2, a simulation model has been constructed and simulation studies have been carried out in ADAMS system. Geometric, mass and inertial parameters of the model have not been presented here due to the scope limitations placed on paper presentations.

3.2. Geometric model of the track

The geometric model of a track includes elements which allow for the analysis of the dynamics at junctions (the so-called ‘passive switch’), in motion on transition curves and tracks of constant radius curves. At the same time, the model must account for the specifics of a two-layer network, in which the maneuver of the change from a constant speed layer to a low speed layer is quite frequent. Moreover, the geometry of the track must take into account the velocity of the vehicle and the requirements concerning dynamic effects on passengers.

4. SIMULATION MODEL

Before the development of a simulation model, the position of its units had been precisely determined. The position and orientation of the model is based on chapter 3 of this paper. In the simulation model of a PRT vehicle the track has been constructed in MBS Adams 2005 R2 system based on the nominal model presented above in chapter 3. The most important characteristics of the model described here, which determine the difficulty of modeling and analysis, are as follows:

-the parts type – rigid
-the number degrees of freedom– 18
-the number of parts – 6
-the topology of the system – open
-the character of motion – three-dimensional

Additionally, a track has been constructed, whose geometry has been discussed in chapter 3 of this paper and paper [2]. A susceptible link between the cabin suspension and the drive system has been modeled by describing the value of stiffness and damping in six coordinates (3 translations, 3 rotations).

The following forces and moments affecting the elements of the system are being modeled:

- gravitational force,
- forces of reaction moments in kinematic pairs,
- forces of interaction between the main support wheels and the track,
- forces of interaction between lateral guide wheels and the track,
- drive forces,
- external wind force,
- constraints imposed by relocating mass inside the cabin.

In this paper the first two groups of forces have not been described as their model is automatically generated by ADAMS pack.

4.1. Interaction between moving vehicle and track

In the system presented here a simplified contact model has been used. Normal forces of interaction F_N between the wheels and the track are modeled as functions of shift and wheel speed relative to the track in the normal direction. These forces are calculated independently for each of the two wheels in point A.

$$F_N = f(x, \dot{x}, d, k, e, c_{max}, h) = \begin{cases} k(d-x)^e - c\dot{x} & \text{for } x < d \\ 0 & \text{for } x \geq d \end{cases} \quad (1)$$

where:

x – the distance between parts,

$\dot{x}$ – relative velocity,

d – the distance at which the contact of the parts occurs,

k – stiffness,

e – exponent,

c_{max} – maximum value of damping,

h – the depth of penetration for maximum damping.

The dependence of damping *c* on the parameter c_{max} and *h* on the temporary depth of penetration $p=d-x$ is calculated by means of a third degree polynomial. This function is used to calculate the value of jump function. It is a continuous function which allows avoids problems during the integration equation of motion. The definition of function is as follows:

$$c = f(x, d, c_{max}, h) = \begin{cases} 0 & for \quad x \geq d \\ c_{max} \cdot \Delta^2 (3 - 2\Delta) & for \quad d - h < x < d \\ c_{max} & for \quad x \leq d - h \end{cases} \qquad where: \Delta = \frac{d-x}{h} \quad (2)$$

The forces of friction between the main wheels and the track in the local direction x and y are determined on the basis of occurring pressure forces F_N, slip and the coefficient of friction. It has an opposite sense to the direction of relative motion (the slip).

$$F_T = -\mu \cdot F_N \quad (3)$$

where:

F_T – friction force

μ – coefficient of friction depending on the slip speed Vp,

r – the radius of running wheels (distance between the wheel rotation axis and the track).

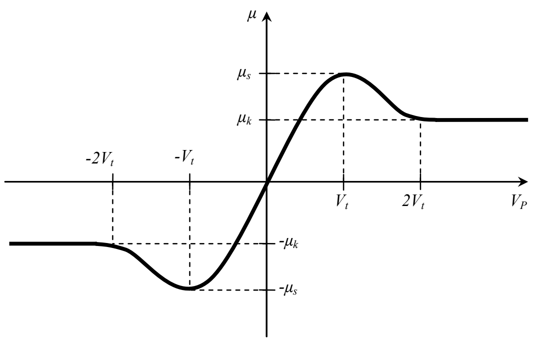

Figure 3. Dependence of the value of coefficient of friction μ on the slip speed V_p

The speed of slip is calculated from the following formula:

$$V_P = r \cdot \omega - V \tag{4}$$

where:

V_p the speed of slip,
r the distance of the wheel rotation axis from the track,
ω the speed of wheel rotation,
V the speed of cabin advancement in the directions x and y respectively.

5. RESULTS

The presented diagrams were selected to illustrate the studied values and their progress in time. In Figures 5 the results of simulation for models E and F have been presented, where E – model without cabin shock absorption and F – model with cabin shock absorption. More diagrams of the researches have not been presented here due to the scope limitations placed on paper presentations.

A simulation with kinematic constraint has been assumed as a nominal ride, which is caused by the geometry of the track characterized by the postulated velocity profile which included acceleration, ride with constant velocity, deceleration and the following ride with constant velocity.

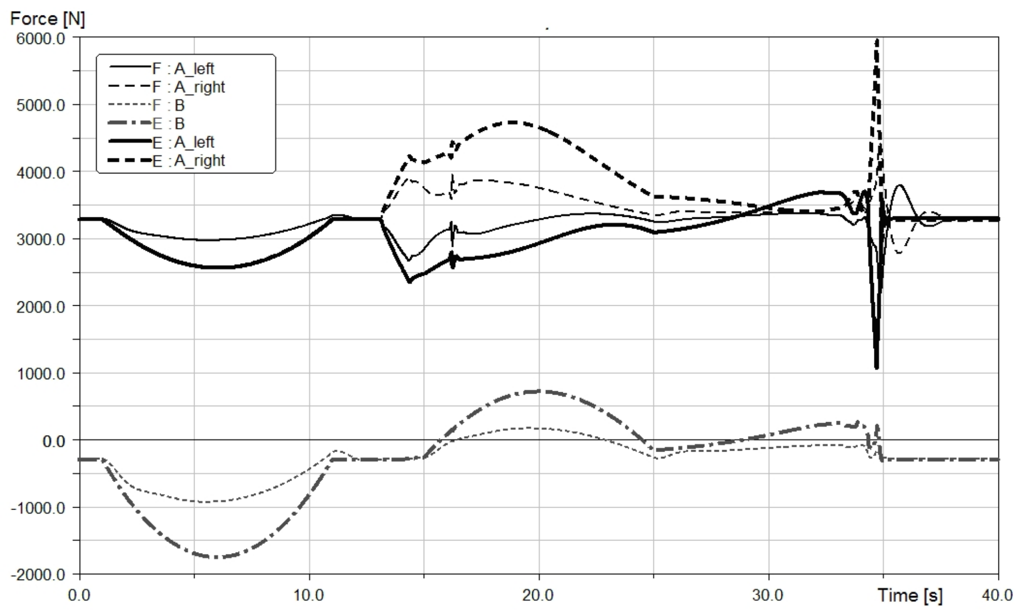

Figure 4. The progress of contact forces in points A and B in the normal direction Z

6. CONCLUSIONS

What follows from simulation studies is several important conclusions concurrent with the conclusions obtained from e.g. the analysis of track vehicle dynamics. By comparing the ride on a straight track with a curved one it is possible to formulate other requirements concerning suspensions, especially lateral ones. The use of adaptation suspension seems to make great sense in case of PRT vehicles. This is one of the first papers in the world dealing with the dynamics of PRT vehicles. The results of simulation studies are used in further MES analyses and contribute to the final model construction of both the PRT vehicle and its drive system. The CAD model of the PRT vehicle in question is presented in Figure 5.

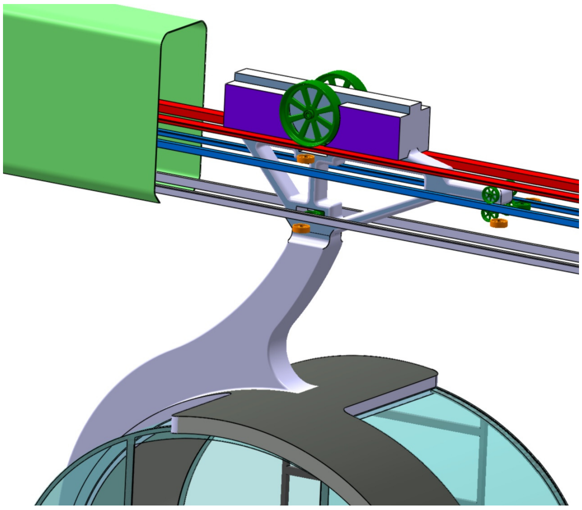

Figure 5. CAD model of a PRT vehicle in CATIA V5 system

The described model has strong parameters and allows for further researches. It will focus on the analysis of the sensitivity of selected dynamic features and parameter changes. There are plans to construct a prototype of the researched model and conduct verification studies of dynamic models described in this paper.

Acknowledgment

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WYBRANE ZAGADNIENIA KOMPUTEROWEGO WSPOMAGANIA PRAC PROJEKTOWYCH POJAZDÓW TRANSPORTU PRT

Streszczenie: Referat dotyczy zagadnień modelowania pojazdów PRT. W pracy przedstawiono krótką charakterystykę transportu PRT ze wskazaniem problemów dynamiki pojazdów. Zaprezentowano strukturę układu napędowo-jezdnego w oparciu o zgłoszenie patentowe na wynalazek, którego współtwórcami są autorzy tego referatu oraz trójwymiarowy model symulacyjny pojazdu systemu PRT (Personal Rapid Transit). Model zbudowano w systemie Adams, służącym do symulacji układów wieloczłonowych (Multibody Systems). Pojazd modelowany jest w sposób uproszczony z zachowaniem parametrów masowych i bezwładnościowych modelu CAD, wykonanego uprzednio w systemie Catia V5. Model uwzględnia zagadnienia kontaktu, tarcia i poślizgu towarzyszące kontaktowi kół jezdnych z szynami oraz rolek prowadzących pojazd w torze. Dokonano badań mających na celu analizę wrażliwości wybranych cech dynamicznych na zmiany parametrów.
Słowa kluczowe: Personal Rapid Transit, dynamika pojazdów PRT, modelowanie i symulacja.