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Simulation research of driveability of the ECO electric car

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Abstract

The paper presents simulation research results of electric car motion processes with special functionality and construction facilitating its use by the disabled. The model of the structure: motor car – human being – environment has been used in the research. Special attention has been paid to the issue of the, so called, driveability of the car driven by a driver with a lower limb disability who is performing this activity from the wheelchair and not the driver seat. The driveability of the car has been assessed based on the technical stability analyses for the conditions of the ”moose test” manoeuvre. The research results have been used in the process of virtual pre-prototyping finalized with the construction of a non-commercial pre-prototype of a car created within the framework of ECO Mobility project. Simulation model of a motor car mechanical systems has been constructed in MBS technology. For description of the tyred wheel, TNO Delft Tyre model has been used. In the model of a control system, the description of programmable systems of the rear wheel drive electronic differential has been included. The model of a driver and the conditions for conducting the “moose test” manoeuvre have been presented.

1. Introduction

The modelled electric car can be driven both by a person with full functional capacity as well as by a person with a motor disability who moves in an active wheelchair. The former drives a car from the position of a car seat, whereas, the latter on – from their own wheelchair. The process of taking a driver seat by a disabled person does not involve any support on the part of persons with full functional capacity.

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Fig. 1. View of pre-prototype motor car. ECO Mobility Conference, Rzeszów, September 2013.

A disabled person enters a motor car on their active wheelchair and takes a seat in front of the driving panel (disabled persons moving on the electric wheelchairs cannot drive a vehicle). The car was called ECO car for short. In order to achieve presented functionality of this car, various systems have been used in its construction creating an innovative solution. The following solutions can be listed here: a flat floor, lowered bodywork, sliding car seat system, placing driving motors in the rear wheels, SBW system (steer by wire), ED system (system of electronic differential), electric brake, sliding driving panel and programmable operating system. Many of these systems affect the vehicle dynamics. In the classic cars, these are first of all, suspension system and control system. In the ECO car developed, the dynamics also depends on the quality of SBW and ED systems, including the software applied. The objective of the conducted simulation research was to verify the influence of construction changes of the bodywork suspension mechanisms and the change in algorithms of electronic differential software system (ED) or electric gear of the steer by wire system (SBW) on the car driveability. Driveability of the car has been assessed based on the technical stability for the conditions of the “moose test” manoeuvre. This type of approach required designing not only a car dynamics model, but a comprehensive model of the system: motor car – human being – environment. Research results have been used in the process of virtual finalized pre-prototyping with the construction of a non-commercial pre-prototype of a car created within the framework of the ECO Mobility project. Fig. 1 presents the photograph of the pre-prototype car. In the course of design work, partial research results were published on the choice of drive system structure and parameters [20], research on the energy consumption of hybrid battery-capacitor source of energy [14], [21], [24], as well as driveability of the dynamics model [19].

2. Model of the driver

In the conducted simulation research, the possibilities have been taken into account of performing several manoeuvres in accordance with the research standards in the industry [8], [18]. One of them is the manoeuvre of avoiding an obstacle, frequently referred to as "moose test" [4]. In order to perform this manoeuvre, a "virtual driver" is needed who models the behaviour of a vehicle driver. Reference books describe various ways of modelling the preset route and vehicle driving methods. As the examples of models used, we can list so called anticipation [1], [5], direction [19], vector [11] or adaptive models [15], [22]. In the discussed simulation model, own model has been used based on simple dependencies of Ackermann model [25] including, however, elements of anticipation of direction control, distance from the track centre and the driver's experience.

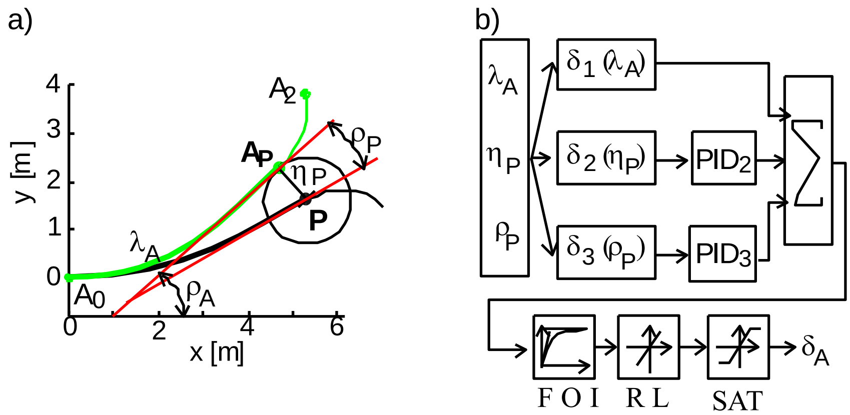

Fig 2. Principle of the driver model operation: a) trajectory analysis, b) structure

A green graph in fig. 2a indicates the preset trajectory of a vehicle front wheel axis centre, whereas, black graph – the trajectory of motion exercised by the model. The points have been indicated in the following way: A_0 – beginning of the preset trajectory of motion, A_2 – end, P – centre of front wheel axis of the model at a chosen moment of the analysis, A_P – projection of point P on the preset trajectory of motion. Location of point P is defined by coordinates [λ_A, η_P], where: λ_A – length of the curve, η_P – distance between the point and the curve. The value characterizing the trajectory in point P can additionally be represented by the angular error of bodywork axis deflection from the preset driving direction indicated in fig. 2a by symbol ρ_P. The operation method of a driver's model is presented in fig. 2b. The input values for calculation were defined earlier [λ_A, η_P, ρ_P]. The turning angle of directional driving wheels indicated in such a way comprises three components related to the driver's skills: *a'priori* prediction of the turning angle distribution along the travelled curve described in fig. 2b as function $\delta_1(\lambda_A)$, angle of reaction to transverse deflection from the preset trajectory described in fig. 2b as function $\delta_2(\eta_P)$ and angle of reaction to the error in the preset direction of driving described in fig. 2b as unction $\delta_3(\rho_P)$. The ultimate reaction of the driver is described by the following elements: inertial (FOI – First Order Inertia), Rate Limiter (RL) and Saturation (SAT). The setting values of these elements for models describing drivers with full functional capacity are presented in the reference books [6], [12], [13].

2. Model of the vehicle

In designing the model of motor car dynamics, a simplified assumption has been adopted that it is presented by means of rigid body systems, connection points between bodies defining mutual freedom of motion and resilient and shock-absorbing elements. The basic model structure is presented in fig. 3. As a basic method of modelling the mechanical system of a motor car, the MBS technology has been adopted [3], [17], [29].

The model comprises tyred wheels (indicated in fig. 3 by symbols WT distinguished by respective indices (L – left, R – right, F – forward, B – backward) and described in a simulation model by library models TNO Delft Tyre [26], suspension systems (indicated in fig. 3 by symbols S), MacPherson strut (in the front suspension indicated in fig. 3 by symbols Mc) and MacPherson strut in the rear trailing wheel (indicated in fig. 3 by symbols Co). Additionally, in the front wheel system there are bodies of steering rods and steering gears (systems indicated by the red colour). Detailed solutions for suspension models and their parameter have been presented in the reference book [19].

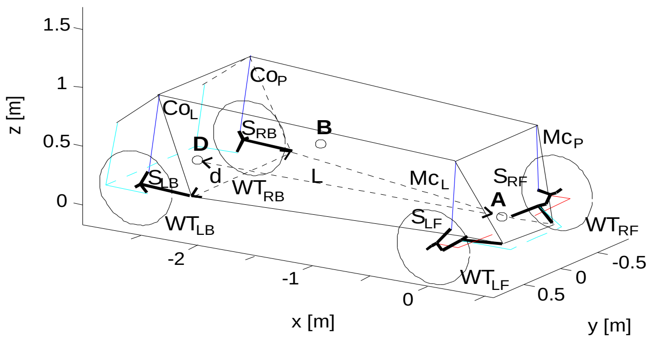

Fig. 3. Structure of the dynamic model of a motor car: B – bodywork centre of mass point, A – front wheel axis centre point, D – rear wheel axis centre point, WT – tyred wheels, S – suspension, Mc – MacPherson strut - front, Co – MacPherson strut - rear, L – distance between the wheels' axes, d – wheel track.

3. Steer by wire and electronic differential systems

In the steering and drive system of an ECO motor car, the function of direction controller is conducted by the steering wheel of SBW system, whereas, the function of speed and torque controller – by pedal or joystick of ED system. At the present moment, the research results are known and the first applications of both SBW systems [2], [9], [28], and ED systems [7], [16], [10], [23], [27] have already been used. Fig 4. presents two basic structures of velocity control used in vehicles with rear wheel drive: a) with direct presetting of two speeds, b) with speed difference presetting. Other topologies have been, among the others, presented in the reference book [19].

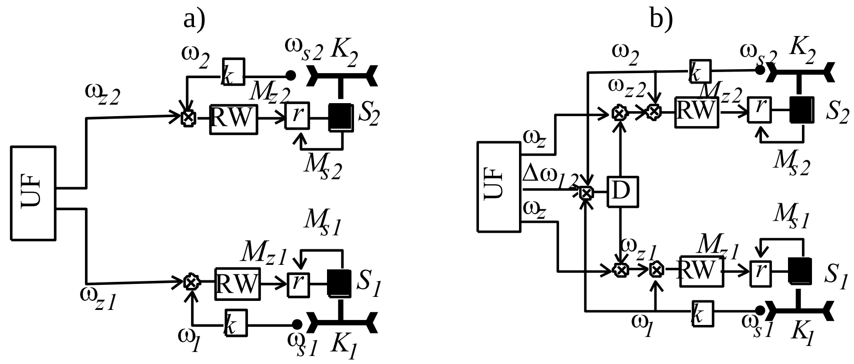

Fig. 4. Topologies of control systems with speed presetting considered for applications in the ECO car designed: a) with direct presetting of two speeds, b) with speed difference presetting. Indications: **UF** – forming system, **RW** – speed controller, **D** – speed difference controller, **A** – average speed controller, S_1, S_2 – electric traction motors, r – traction motor controller, k – correction element, $\square_{zA}$ – preset angular velocity of virtual spur gear in the centre point of the front axis A, $\square\square_{zA}$ – preset angular velocity difference of a wheel in relation to virtual spur gear, $\square_{z1}$, $\square_{z2}$ – preset motor angular velocities, $\square\square_{12}$ – preset speed difference

4. Simulation research for the “moose test” conditions

Fig. 5 presents simulation results of the distance between the centre point of the car and the road axis as the function of the travelled distance described by the relationship $_P(\lambda_A)$, where, as in fig. 3: λ_A – length of the curve, η_P – distance between the point and the curve wherein the curve is the preset trajectory of an ideal manoeuvre. The calculations have been conducted at the assumed constant speed of 50 km/h (it is maximum admissible design speed). A constant parameter of calculations was the angular velocity of front wheels turn of the SBW system. Fig. 5 presents a family of distance distributions for the following values of angular velocity of the front wheels turn: 13, 15, 40, 75 ^{o}/s. Horizontal red lines indicate the borders of road lane (0.75 m from road axis on each side). The driving is stable if the trajectories of motion points of its centre fit in the admissible road lane. The simulation results obtained show that for the final execution of the test, angular velocity of the front wheels turn of at least 40 °/s is needed. Based on this, the angle of gear ratio of the intersecting axis gear and electric gear of SBW system can be selected. For example, providing the maximum angle of the front wheels turn equal to 35 °/s is obtained through 1.25 turns of a steering wheel, the driver would have to turn the steering wheel at least at the angular velocity of 514 °/s, with the 0.5 of a turn – over 206 °/s, and for 0.25 of a turn – only 90 °/s. More simulation results of the "moose test" drive have been presented in the reference book [6]. Taking into account analyses results of the change of lane manoeuvre (for the vehicle nominal speed of 10.56 m/s) and the "moose test" manoeuvre (13.6 m/s) angular gear ratio of SBW gear of the value of 5.142 can be selected for the vehicle (180° of the steering wheel turn corresponds to 35° turn of front wheels). At this gear ratio, minimum values of angular velocity of the steering wheel turn equals about: 50 °/s (change of lane) and 200 °/s (moose test).

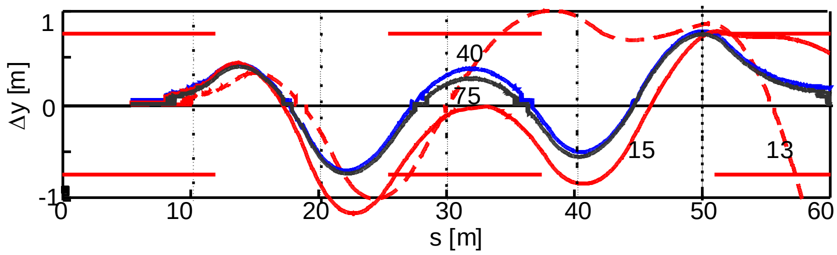

Fig. 5. Distances from the centre of road axis in moose tests at the speed of 50 km/h with various limits of front wheels turn velocities: 13, 15, 40, 75 °/s.

4. Summary

The present article discusses the methodology of stochastic and technical stability analysis of a car model, which facilitates the choice of various construction solutions in accordance with the rules of virtual pre-prototyping. As an example of the application of this methodology, analyses results have been presented of the influence of the value of intersecting axis gear and electric gear of the SBW system on stability of the manoeuvre called "moose test". Results of these analyses and stability analyses for other relationships not discussed in the present paper have been used in the construction of a non-commercial pre-prototype of a car.

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