Controll Function on Active Tilting Train Based on an Appropriate Multibody Mechanical System

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The present paper deals with the problem of controller function in active system of tilting in high speed railway vehicles, which is based on different mechanical models of railway vehicles. According to the classical mechanical model of the vehicle, an appropriate mechanical multibody system is formed in this paper. In conformity with the basic constructive parameters of the active system of tilting, guidance control function of actuator operating process is formed. Basic mechanical model, in dependence of characteristic constructive parameters, according to the theory of robust robotic control is given in the form of closed kinematics chain with branching. For the concrete model of high speed railway vehicle, differential equations of motion are obtained in the form optimal for control function evaluation and calculation.

Keywords: *differential equations, tilting train, kinematics chain, guidance control function.*

1. INTRODUCTION

Active tilting systems technology shown in Figure 1 that are developed by various railway manufacturers as Alstom, Hitachi, CAEF, Adtranz, Alstom, Fiat, etc., permit rail vehicles to negotiate bends with higher lateral accelerations that would be defined by centrifugal acceleration (1 m/s^2) that passengers can normally tolerate.

A new generation of tilt control system consists of three newly developed technologies: position detection, tilt angle pattern and new electro hydraulic tilt actuators (EHA) instead of electro mechanic actuators. According to the [1], the realization of vehicle's optimal tilting during its movement in a curved track is shown in Figure 1. Additional tilting is obtained by applying the active system of actuators control shown in Figure 2. During implementation of active tilting system of actuators [2], according to the UIC and ORE standards, corresponding values of pitching angle must not be greater than $\varphi \leq \varphi_{max} = 8°$, while the angular velocity and acceleration are 4° /s, and 1° /s^2.

2. TILT CONTROLLER FUNCTION

As acceleration of 1 m/s^2 is the maximum imposed by passenger comfort, assuming the track camber at 0.150 m the speed permitted at the curve is calculated as $v = 5\sqrt{R}$, where R is curve radius in meters [3]. If the vehicle body is also permitted to lift to an extent that corresponds to an additional camber of 0.150 m, then the permitted speed becomes $v = 5.7\sqrt{R}$. If the value of additional camber is increased to 0.200 m, that corresponds to a body lift of 8°, then the resulting maximum permitted speed through the bend becomes $v = 6.1\sqrt{R}$. Accordingly, it follows that it is possible to increase speed by 25 – 30 % compared with the normal state of affairs.

In respect to the Figure 2 and 3 the function of active tilting control $\varphi(t)$ [4] for concrete values of vehicles constructive parameters can be numerically expressed by the following relation

$$\varphi(t) = \alpha\, t^2 + \beta\, t\,[\mathrm{rad}]\,,\; t \leq 3\ \mathrm{s}\,, \tag{1}$$

$$\alpha = 0.01 \div 0.02\,,\; \beta = 0.05 \div 0.10 \tag{2}$$

where t is optimal time of actuator acting.

3. MECHANICAL MODELS OF THE TILTING TRAIN

Classical mechanical model of railway vehicle with 7 degrees of freedom [5] for obtaining controller function is shown in Figure 4.

According to the classical mechanical model of the vehicle [5], it is formed an appropriate mechanical myltybody system that represents the vehicle's secondary motion on the curved track.

Multibody mechanical model [3,6] of railway vehicle with 7 degrees of freedom in a form of open and closed kinematic chains for obtaining controller function is shown in Figure 5.

According to this model, the following generalized coordinates are used [7]: vertical and lateral displacements of vehicle's sprung mass (q_1, q_2), pitching angle of vehicle's sprung mass (q_3), vertical and lateral displacements of powered bogies (q_4, q_5) and (q_6, q_7) and tilt controller function

$$q_8 = \varphi(t) = \alpha\, t^2 + \beta\, t\,. \tag{3}$$

In this model the bodies 1, 2, 4, 6 and 8, are fictive bodies with null inertial and geometric characteristics, while the active tilting system is represented with bodies numbered with 8, and generalized coordinate $q_8 = \varphi(t)$.

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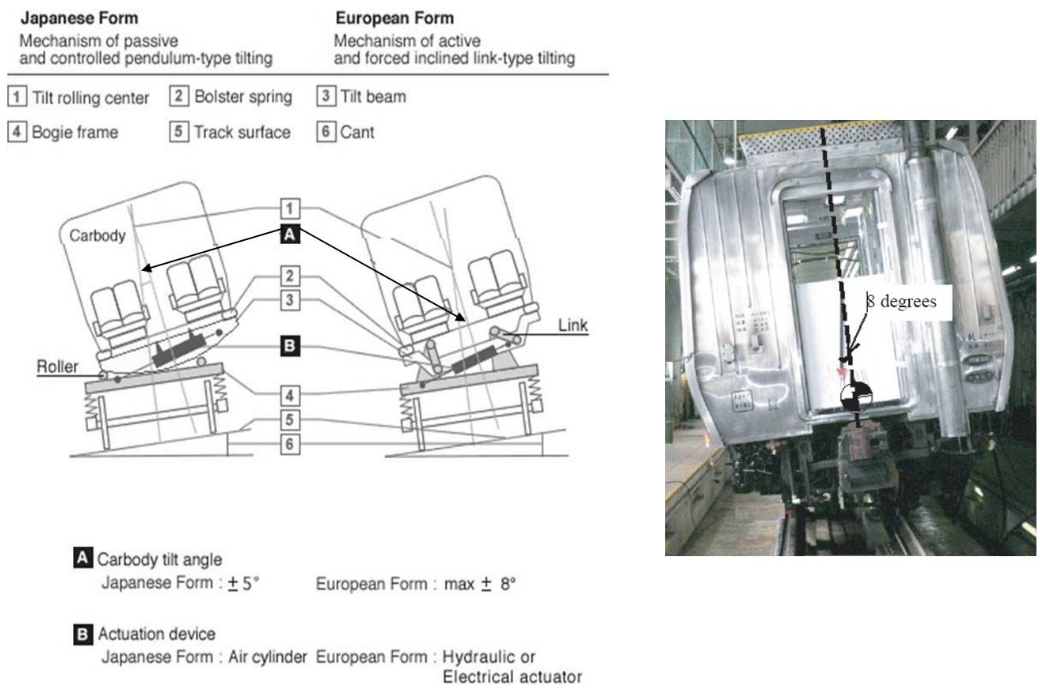

Figure 1. European and Japanese form of tilting type mechanisms

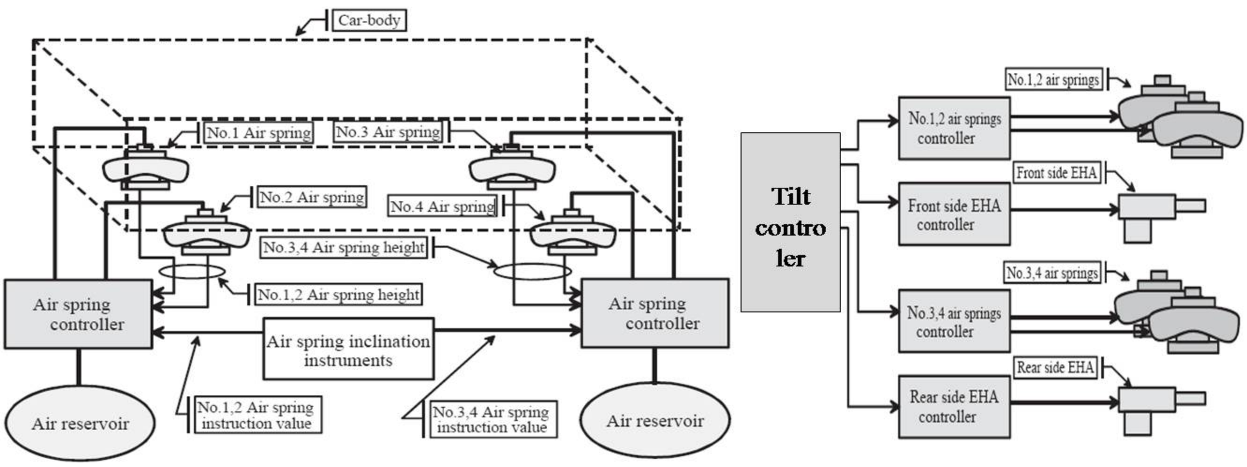

Figure 2. Model of active system of suspension on tilting train

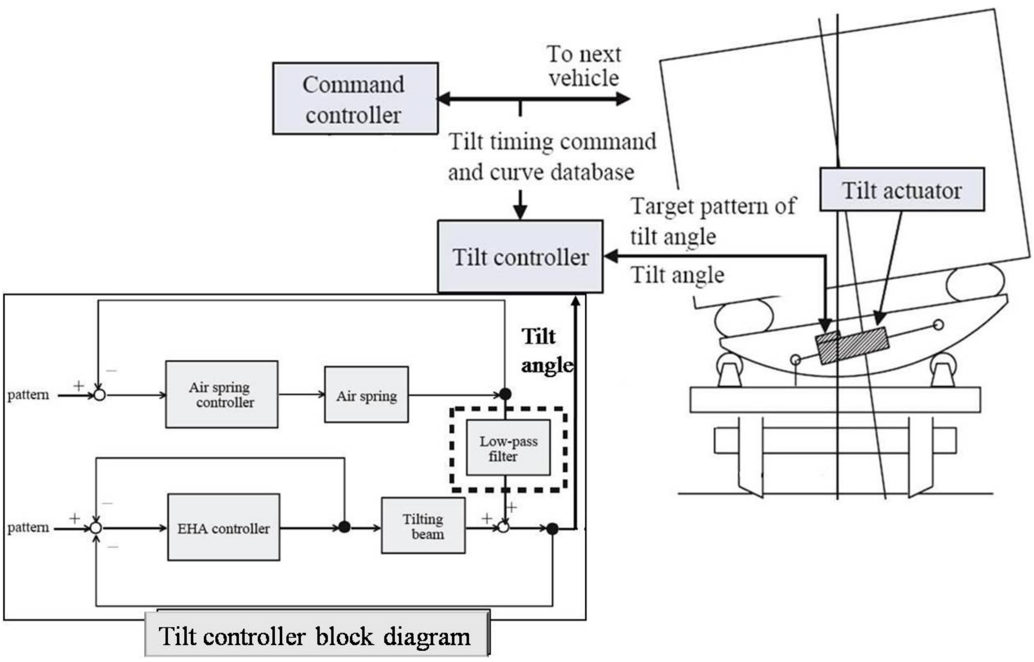

Figure 3. Controller block diagram of tilt actuator

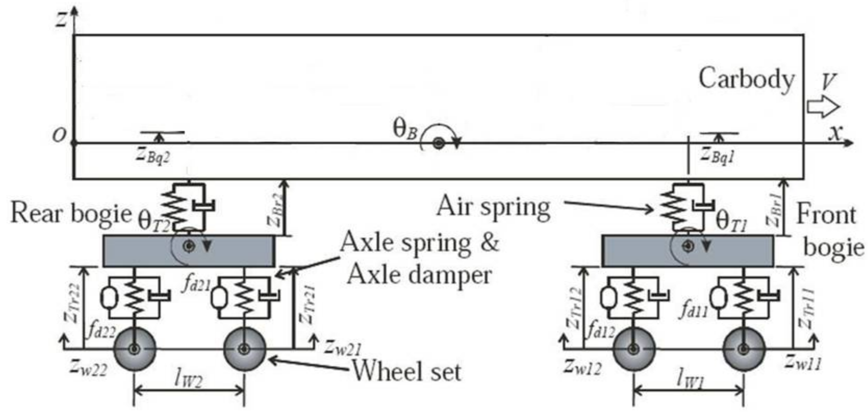

Figure 4. Classical mechanical model of tilting train [5]

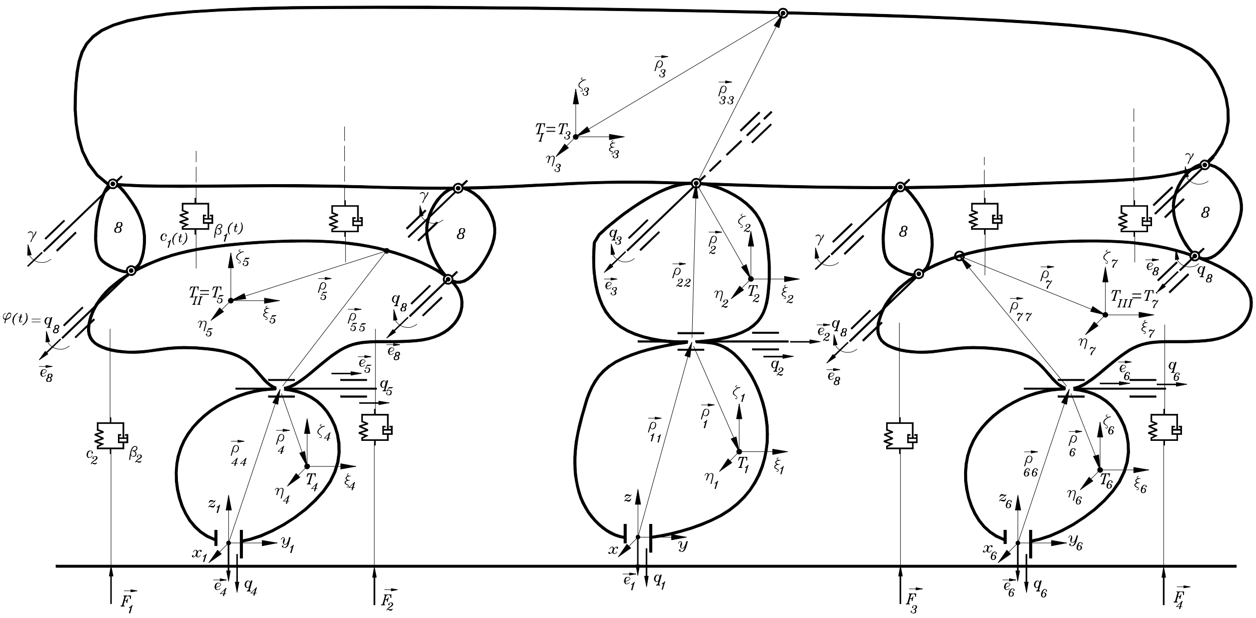

Figure 5. Advanced mechanical model of tilting train in the form of kinematical chains

Differential equations of secondary vehicle's motion are given by the following expression [8]

$$a_{\alpha\beta}\ddot{q}^{\beta} + \Gamma_{\beta\gamma,\alpha}\dot{q}^{\beta}\dot{q}^{\gamma} = Q_{\alpha}, \alpha, \beta, \gamma = 1,...,\text{n}\,, \quad (4)$$

where

- $a_{\alpha\beta}$ are covariant coordinates of the basic metric tensor,
- $\Gamma_{\beta\gamma,\alpha}$ are Christoffel's symbols of the first kind and
- Q_{α} are generalized forces.

Covariant coordinates of the basic metric tensor are expressed by the relation [9]

$$a_{\alpha\beta} = \sum_{i=\beta}^{n} m_i \left(t_{\alpha i}^{(\alpha)} \right) \left\{ t_{\beta i}^{(\alpha)} \right\} + \left(e_{\alpha i}^{(i)} \right) \left[J_i \right] \left\{ e_{\beta i}^{(i)} \right\}, \quad (5)$$

where

- $\left\{ t_{\alpha i}^{(\alpha)} \right\}$ is quasibase vector expressed in α coordinate system of reference,
- $\left[J_i \right]$ is tensor of inertia of the i-th body and
- $\left(e_{\alpha i}^{(i)} \right)$ is unit vector of corresponding generalized coordinate in i-th system.

Quasibase vector expressed in α coordinate system of reference is equal to

$$\left\{ t_{\alpha i}^{(\alpha)} \right\} = \frac{\partial \{ r_i \}}{\partial q_{\alpha}}, \quad (6)$$

while another quasibase vector also represented in α coordinate system is

$$\left\{ t_{\beta i}^{(\alpha)} \right\} = \left[A_{\alpha\beta} \right] \left\{ t_{\beta i}^{(\beta)} \right\}, \quad (7)$$

where $[A_{\alpha\beta}]$ is multiply matrix of transformation between β and α coordinate systems.

Christoffel's symbols of the first kind are expressed in the following way

$$\Gamma_{\beta\gamma,\alpha} = \frac{1}{2}\left(\frac{\partial a_{\gamma\alpha}}{\partial q^{\beta}} + \frac{\partial a_{\alpha\beta}}{\partial q^{\gamma}} - \frac{\partial a_{\beta\gamma}}{\partial q^{\alpha}} \right),$$

$$q_{\alpha,\beta,\gamma} = \varphi_{\alpha,\beta,\gamma} \wedge u_{\alpha,\beta,\gamma}\,,$$

$$\Gamma_{\beta\gamma,\alpha} = 0, \qquad \forall\, q_{\alpha,\beta,\gamma} = u_{\alpha,\beta,\gamma}\,. \quad (8)$$

To obtain the generalized forces that consist of conservative, nonconservative and control forces on the right sides of differential equations

$$Q_{\alpha} = Q_{\alpha}^{c} + Q_{\alpha}^{nc} + Q_{\alpha}\left(\varphi(t)\right), \quad (9)$$

it's necessary to analyze the closed kinematics chain without branching.

4. CONCLUSION

To improve the performance and riding comfort of tilting train it is now used tilt control system that has three newly developed technologies, position detection, tilt angle target pattern and new electro hydraulic tilt actuators (EHA). According to the classical model of active tilting railway vehicle, appropriate multibody mechanical model obtains covariant coordinates of the basic metric tensor, and Christoffel symbols of the first kind in optimal matrix form suitable for computer implementation for automatic formulation of nonlinear differential equations of vehicle oscillatory motion. Multibody mechanical model enables faster and accurate forming control function $\varphi(t)$ of actuator action. It allows complex analysis of the influence of each introduced parameter on increasing velocity and stability of tilting trains. As each of these parameters could be varied in corresponding boundaries, in that way the influence of any of the introduced parameters could be examined with the purpose to increase velocity and stability of tilting trains.

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ФУНКЦИЈА УПРАВЉАЊА АКТИВНИМ НАГИЊАЊЕМ ВОЗА ЗАСНОВАНА НА ОДГОВАРАЈУЋЕМ МЕХАНИЧКОМ СИСТЕМУ КРУТИХ ТЕЛА

Срђан Русов, Зоран Митровић, Никола Младеновић

У раду се разматра проблем оптимизације функције управљања контролера активног система нагињања код возова великих брзина, заснован на анализи различитих механичких модела железничких возила великих брзина са самонагињањем. У складу са класичним механичким моделом возила формиран је одговарајући механички модел у облику система крутих тела представљеног у виду кинематичких ланаца. Формиран је одговарајући блок дијаграм и функција управљања активног система самонагињања возила са електрохидрауличким актуаторима, за чију основу је предложен осавремењени механички модел возила, који омогућава оптималну форму диференцијалних једначина кретања возила у које је интегрисана одговарајућа управљачка функција.