International Journal of Automotive Technology (2024) 25:663–672
https://doi.org/10.1007/s12239-024-00052-4

BODY AND SAFETY, CHASSIS, HUMAN FACTORS AND ERGONOMICS, MATERIALS AND RECYCLING, NOISE, VIBRATION AND HARSHNESS, TRANSMISSION AND DRIVELINE, VEHICLE DYNAMICS AND CONTROL

Enhancing Train Coupling Simulation by Incorporating Speed-Dependent Energy Absorber Characteristics Through a Deep Neural Network

Jun Hyeok Hwang[1,2] · Hyun Seung Jung[1,3] · Jin Sung Kim[1] · Seung Ho Ahn[1] · Hyung Gyeun Gil[4]

Received: 14 September 2023 / Revised: 28 December 2023 / Accepted: 2 January 2024 / Published online: 15 February 2024

Abstract

Recently, hydrostatic buffers have emerged as energy-absorbing components in railway vehicles. These buffers exhibit speed-dependent characteristics, with their reaction forces contingent upon compression displacement and speed. However, when dealing with a hydrostatic buffer with an unknown characteristic function in dynamic simulations, accommodating its speed-dependent attributes becomes a challenging task. In this study, we proposed a method for simulating train couplings that incorporates the speed-dependent characteristics of a hydrostatic buffer by utilizing a deep neural network (DNN). Our methodology involved the training of a DNN-based speed-dependent buffer model using empirical data obtained from dynamic buffer tests. Subsequently, this model was applied to a multibody dynamics simulation for train coupling analysis. A critical aspect of this study involved comparing speed-dependent and speed-independent models in a train coupling scenario. This comparison reveals a significant insight: neglecting speed-dependent characteristics in coupling simulations can lead to inaccurate train-coupling safety assessments. The DNN-based method demonstrated its effectiveness, even with limited test data and when the mathematical speed-dependent characteristic function of the buffer is unknown.

Keywords Hydrostatic buffer · Speed-dependent characteristics · Train coupling simulation · Deep neural network · Multibody dynamics

List Symbols

$\boldsymbol{M}$	Mass matrix
$\boldsymbol{f}$	Force vector
$\boldsymbol{x}$	Position vector
$\dot{\boldsymbol{x}}$	Velocity vector
$\ddot{\boldsymbol{x}}$	Acceleration vector
μ	Coefficient of friction
g	Gravitational acceleration
f_{s}	Static friction
f_{k}	Kinetic friction
$f_{\mathrm{buffer}}^{t-\Delta t}$	Reaction force of buffer at time $t-\Delta t$
Δd	Change in displacement
$K_{\mathrm{transition}}$	Transition stiffness

✉ Hyun Seung Jung
jhs@krri.re.kr

1 Railroad Accident Research Department, Korea Railroad Research Institute, Uiwang, Republic of Korea

2 Department of Robotics and Virtual Engineering, Korea University of Science and Technology, Daejeon, Republic of Korea

3 Department of Transportation System Engineering, Korea University of Science and Technology, Dajeon, Republic of Korea

4 Technical Research Center, KOBA, Seoul, Republic of Korea

1 Introduction

Trains are frequently coupled and decoupled for various operational needs, such as formation changes, rescue operations, and shunting. In the coupling process, a moving train collides with a stationary one with engaged brakes. However, due to the substantial kinetic energies involved, even at low speeds, trains or their couplers may suffer damage if this kinetic energy is not efficiently dissipated during the collision. To mitigate these risks and ensure safety, energy-absorbing components such as draft gears and hydraulic or