Mechatronics 21 (2011) 1108–1122

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Integrated tilt with active lateral secondary suspension control for high speed railway vehicles

Ronghui Zhou, Argyrios Zolotas *, Roger Goodall

Control Systems Group, Department of Electronic and Electrical Engineering, Loughborough University, Loughborough LE11 3TU, UK

ARTICLE INFO

Article history:
Received 19 July 2010
Accepted 3 July 2011
Available online 4 August 2011

Keywords:
Railway vehicle dynamics
Active lateral suspension control
Tilt control system
Estimator-based control

ABSTRACT

This paper presents a novel active suspension control configuration for high speed tilting railway vehicles which integrates tilt with active lateral secondary suspension. The use of the active lateral secondary suspension is to attenuate the vehicle body lateral vibration on straight track, while complementing tilt action during curving. Various control strategies are proposed to accommodate both tilt and active lateral suspension multiple design requirements, whilst considering the strong interaction between vehicle body roll and lateral modes. Compared with the commercial solutions for tilt control, the proposed integration strategy improves the tilting control performance both on curved and straight track as illustrated by simulation tests and control assessments based on given track profiles.

1. Introduction

Tilting trains are now well accepted within the rail industry as a means to operate at higher speeds compared to conventional trains, without the need to upgrade rail infrastructure. The idea is quite straightforward, based upon tilting the vehicle body inwards on the curve to compensate the larger lateral acceleration that would otherwise be perceived by the passenger at higher speed. Early passive tilting trains completely relied upon the natural pendulum motion laws which caused safety issues, i.e. vehicle body over turning [1]. A tilt mechanism (tilting bolster in most cases) in conjunction with an actuator to tilt the vehicle body was introduced afterwards, which has become a standard technology used in trains worldwide.

Fig. 1a shows a typical mechanical configuration, the example type being the Swedish X2000 tilting train which is currently running between Stockholm and Gothenburg. In this configuration, wheelsets are connected to the bogie via stiff primary suspension elements, which are designed to meet vehicle stability and guidance requirements. Each bogie has four wheels arranged in two pairs, where each pair is rigidly connected via a common axle (known as the solid-axle wheelset). A tilting bolster is connected to the bogie by inclined swing links, and actuators fitted between the bogie and the bolster create the tilting action below the secondary suspension. The tilting bolster is able to provide a maximum tilt of up to 10°, and the inclined link arrangement means that the effective tilt center is above the vehicle body floor level. A pair of airsprings are located between the body and the bolster, and combined with dampers forms the soft passive secondary suspension. This isolates the high frequency vibrations from the bogie and provides an appropriate passenger ride comfort.

The curved sections on railway tracks are “canted” inward towards the center of the curve, as shown in Fig. 1b, which reduces the lateral (curving) acceleration experienced by the passengers. The resultant lateral acceleration is known as cant deficiency (D, m/s^2), and is given by (in the case of non-tilt trains):

$$D = \frac{v^2}{R} \times cos(\theta_0 - |\theta_v|) - g \times sin(\theta_0 - |\theta_v|) \qquad (1)$$

where v is the vehicle forward speed, θ_0 is the track cant angle, θ_v here is the outwards vehicle body roll angle, R is the track curve radii and g is the constant of gravity. However, cant deficiency is most often defined as an angle ($\theta_{dm} = D/g$) presenting the difference between the existing cant angle (θ_0 in (1)) and the angle required to fully eliminate the effect of centrifugal force at maximum allowable speed [1].

Higher speeds through curves with conventional tracks can only be achieved by lengthening transitions and increasing curve radius, which is very expensive and in some cases impossible. Alternatively, tilting effectively reduces the cant deficiency by leaning the vehicle bodies further towards the curve center. The passenger curving acceleration in tilting trains can be calculated by following equation,

$$D = \frac{v^2}{R} \times cos(\theta_0 + |\theta_v|) - g \times sin(\theta_0 + |\theta_v|) \qquad (2)$$

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* Corresponding author. Tel.: +44 (0)1509 227085.
E-mail addresses: r.zhou@lboro.ac.uk (R. Zhou), a.c.zolotas@lboro.ac.uk (A. Zolotas), r.m.goodall@lboro.ac.uk (R. Goodall).

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doi:10.1016/j.mechatronics.2011.07.001