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Short communication

Investigation of a four-bar linkage for joining track carriages

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ABSTRACT

A linkage configuration, joining two carriages by two linkage bars, is configured to form a symmetric inverted crossover four-bar linkage. The linkage kinematics is described, and modelling of carriage train motion from a straight section to a uniformly curved section is performed, with the purpose of investigating carriage motion interdependence. Results indicate that, by appropriate selection of the geometric parameters of the carriage linkages, the effective (chord) length of each carriage, measured between endpoints of consecutive carriages, may be reduced upon entering a curved section. Hereby, the train polygon effect, causing unevenness of motion in open and closed carriage chains, may be significantly reduced on a local level.

1. Introduction

Linked carriages, following a track with straight and curved sections, will commonly describe a chord on a fully or partially curved section, as indicated in Fig. 1. By the chordal effect, a carriage, upon entering a curved section, will span a section of track with an arc length which is longer than the straight section the carriage is leaving. Consequently, even for a nominally constant train speed, carriages entering a curved section at a constant speed must accelerate the carriages in front, and conversely when leaving. This effect is clearly visible (and audible) on simple segmented garage gates.

If, upon entering the curved section, the carriage endpoint CE were to maintain a constant velocity v similar to the start point CS, the carriage should conform to the track (CS to CE'). With a rigid carriage, the endpoints instead describe the chord CS to CE, and the average velocity of the carriage endpoint CE is larger than v, implying a curvilinear acceleration. The error may be described by an angle ($\psi - \psi'$) or a length of arc (r•($\psi - \psi'$))

When the carriage has fully entered the curved track, elementary geometry yields

$$\psi' = L/r \tag{1}$$

and

$$\psi = 2 \cdot sin^{-1}\left(\frac{L}{2r}\right) \tag{2}$$

where

L: Carriage length from CE to CS

r: Curve radius

Abbreviations: r [m], Radius of curved track; ψ [], Track angle of carriage endpoint; CS, CE, Carriage start- and endpoints; v_n [m/s], n'th carriage endpoint velocity; L [m], Carriage length; n [], Carriage counter; θ [], Angle between consecutive carriages; p [ ], Train position counter; γ [], Linkage included angle; AB [m], Coupling link length; ACB [m], Carriage cross member length; δ [m], Carriage overlap; L_n [m], Carriage net length; Δ [m], Track conformity error; ψ_e [], Error angle All angles in radians.

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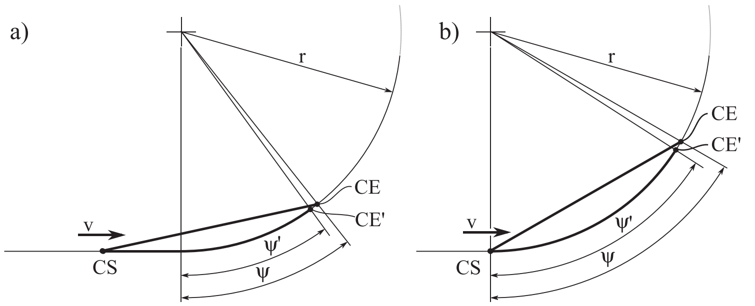

Fig. 1. Chordal effect by single carriage, length L, where carriage start and end points (CS and CE) follow a straight track onto a uniformly curved track. The carriage start point velocity is v. (a): carriage partially on curved track, (b) carriage fully on curved track.

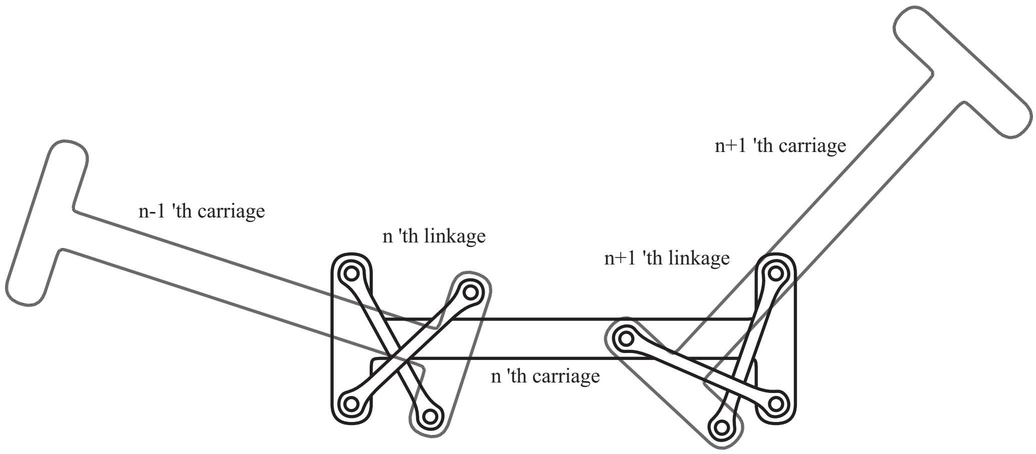

Fig. 2. Linkage outline, carriage n linked to previous and following carriages $n-1$ and $n+1$.

For moderate curvature (i.e. curve radius r is much larger than the typical carriage length L) and open end carriage trains, such as is typical for railways and trains, the chordal effect may be neglected. For closed carriage loops, such as the endless linked conveyor trains used in airport luggage sorting plants, carriages describe a polygon (and the effect is referred to as a polygon effect). A parallel, well-known example is drive chains on bicycles and motorcycles, which must be mounted with a bit of slack to avoid excessive wear. The problem is treated in common textbooks on drive chain design. Mahalingam [1] described the equivalent dynamic loading of a chain. In combustion engines, chains are often used to connect crankshaft and camshafts to obtain an angular velocity ratio of 2:1 required for valvetrain operation in four-stroke engines. For high-performance engines, torsional vibrations in crank- and camshafts may be inadvertently excited by the chain polygon effect; this was discussed in an article on valve train timing drive damping by Lievesley [2].

The endless conveyor train problem was investigated in detail by Ebbesen [3] and Sørensen et al. [4,5], considering carriages joined by simple revolute joints. While it is possible to design track/carriage combinations that eliminates the total polygon effect (meaning that the necessary total length of the closed-loop train is constant regardless of the immediate configuration), the individual carriage velocity will still be subject to variations, which may manifest itself as tensile or compressive waves travelling along the train. Furthermore, specific solutions often require elaborate design of the curved tracks.

For these reasons, design of a means to counter the chord/polygon effect on the individual carriage level is of considerable interest. A carriage linkage which could reduce the effective carriage length to describe the chord CS to CE would be a useful device in that respect.

2. Linkage concept

In the present paper, a mechanism is proposed which may be suited for this purpose. It consists of a crossed four-bar linkage, inverted with a certain overlap between the frames of consecutive carriages. The link configuration is outlined in Fig. 2.

The combined system consists of track, carriages and linkages. For a concise description, the nomenclature is described below. The device is previously published in a patent application [6].