Mechanism and Machine Theory 121 (2018) 1–14

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Research paper

A compact formulation for constant velocity joint kinematics

William Schroeder Cardozo*, Hans Ingo Weber

PUC-Rio - R. Marquês de São Vicente, RJ 225, Brazil

ARTICLE INFO

Article history:
Received 17 June 2017
Revised 11 August 2017
Accepted 12 October 2017

Keywords:
Rzeppa
Homokinetic
Joint
Powertrain

ABSTRACT

This work presents a compact method to analyze the constant velocity joint (CVJ) kinematics. Almost every front-wheel drive cars have four CVJs in the front axle. In the literature, general purpose multi-body dynamics software gives the full dynamics and force analysis through numerical simulations of CVJs. If the CVJ is part of a more complex system, the general purpose software requires too much computational effort. The modeling of a CVJ as a double cardan offers a bypass to this limitation using three sequential rotations around orthogonal axes, which lead from the input axis to the output axis of the joint. In this work, the CVJ model requires only one rotation around the Euler vector defined in a plane. A physical explanation for this single rotation is presented. A kinematic analysis is presented with focus on the output axis embarked angular velocity. A direct method to calculate the position of the spheres for two race track shapes is proposed. The results section presents the movement visualization of the system and the embarked angular velocity for particulars cases. The advantage of the proposed compact kinematics model is that it leads to a more compact dynamic model of the CVJ.

1. Introduction

Traditionally, the coupling for torque transmission between two unaligned axes is done through an universal joint or through a constant velocity joint (CVJ). The CVJ, also called homokinetic joint, is used mainly in automotive vehicles. In front-wheel drive cars, CVJs are widely seen in the front axis. The ball-track principle of this coupling joint was introduced by William Whitney in 1908 [1] in a compact size CVJ. However, only in 1934 Rzeppa [2] developed a practical and reliable CVJ, Fig. 1.

Until today, the CVJ follows the principles of the Rzeppa joint of 1934. In this joint there are six spheres held in a plane that passes through the articulation center by a cage. These spheres run between an outer and an inner race which are not concentric and the cage avoids that the spheres fall off from the joint. Hence, the result of this kinematic restriction holds the spheres in a bisecting plane. A more comprehensive explanation about the CVJ principles and its history can be found in the book of Seherr-Thoss et al.[3]. Most of the work about CVJ involves the analysis of the vehicle powertrain.

Masarati [4] presents a kinematic formulation for the relative orientation of two connected bodies using the Euler vector. A general-purpose kinematics constraint formulation is revealed with several examples. In [5], Masarati and Morandini, and in [6], Morandini et al., proposed a compact formulation for real-time simulation of an ideal homokinetic joint. The work focuses on the tiltrotor of an aircraft, where the torque is transmitted through a scissor mechanism, but the kinematic relation between the axes is similar to a CVJ. This kinematic relation is considered as a double cardan arrangement under

* Corresponding author.
E-mail addresses: billi83@globo.com (W.S. Cardozo), hans@puc-rio.br (H.I. Weber).

https://doi.org/10.1016/j.mechmachtheory.2017.10.009
0094-114X/

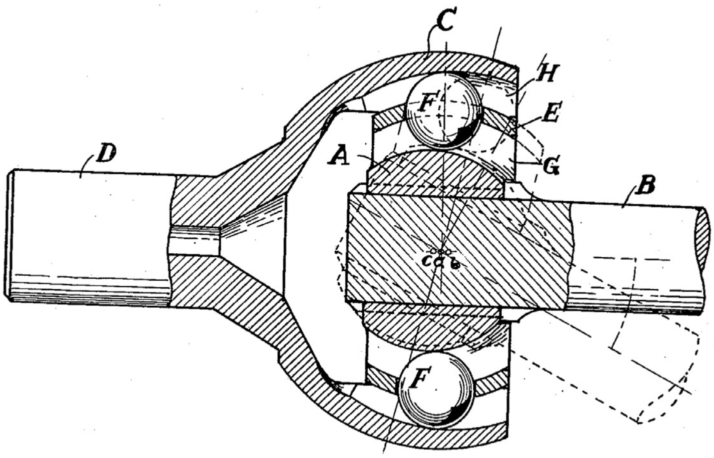

Fig. 1. Rzeppa joint of 1934 (US patent 2,046,584).

the homokinetic condition of Myard's theorem [7]. In the present paper, an even more compact formulation is presented. A direct method to obtain the kinematics of the CVJ is proposed without assuming that it behaves as double cardan under homokinetic condition.

A dynamic analysis is conducted by Kimata et al. [8] considering the friction between the moving parts of a CVJ. Experiments validated the numerical results [9]. The analysis focuses on the internal forces of the CVJ. In a multibody dynamics study of a system where the CVJ is an element of a more complex system, like an automotive vehicle, this kind of modeling leads to a too complex model.

Bellomo and Palamara Orsi [10] performed a dynamic model of a CVJ with straight tracks. The authors proposed a kinematic model based on a set of axioms. Due to the limited processing capacity of computers at that time, for the numerical simulation a simplified model is obtained through a Fourier expansion. The analysis of the system dynamics is limited to a constant articulation orientation.

Pennestrì et al. [11] analyzed through numerical simulations a CVJ with straight tracks and geometric errors. A numerical example shows the influence of the manufacturing error in an industrial CVJ. A closed form kinematics is proposed for straight crossed tracks. Through a forth order polynomial equation the relation between the input and the output axis is obtained.

Watanabe et al. [12] show the velocity fluctuation of circular tracks CVJ with manufacturing error. This analysis is restricted to axes with fixed direction.

There are other interesting papers [13–16] dealing with the internal forces of the CVJ through the analyses of the cage, sphere and groove interaction.

Pennestrì and Valentini [17] and Fischer and Lawson [18] showed that the older Rzeppa joint with a pilot-lever does not hold the spheres in the homokinetic plane for any relative orientation of the input and output axes. Pennestrì et al. [19] proposed a method to minimize the angle between the plane of the spheres and the bisecting plane in a Rzeppa pilot-lever joint. Using a general purpose multi-body dynamics software, the contact forces acting on the spheres are calculated.

Novel designs for CVJ have been proposed. Watson et al. [20] presented a novel conceptual design of a CVJ composed by a robust double cardan mechanism. A straight track CVJ with wide articulation angle is proposed by Hoshino and Funahashi [21] and Kobayashi [22]. Yaghoubi et al. [23] presented a constant velocity mechanism to transmit torque between to axes with up to 135° of articulation angle.

Cardozo and Weber [24] developed a 2-dof parallel electrohydraulic-actuated homokinetic platform, similar to a thrust vector control (TVC) device. The proposed platform has a moving table supported by a CVJ with two electrohydraulic actuators in parallel. In [24], the kinematic formulation proposed here is used to analyze the device. Also in [24], the developed model is implemented to perform numerical simulations, which are validated with experimental data.

In this work a rotation matrix is proposed to state the relation between the input and the output axis of the CVJ. The kinematic model is implemented in Matlab software to perform visualizations of the mechanism. The differences and similarities between two types of CVJ are shown. This class of joints is called CVJ because two axes connected through this joint have the same angular velocity; however, usually the orientation of the axes is considered constant [3,8–11]. In [5] a more general case is studied, but the CVJ is considered as a double cardan. In this work, the same expression as in [5] is obtained for the angular velocity around the output axis, but with a different approach.

The kinematic analysis begins proposing a rotation matrix that leads from the input axis to the output axis of a CVJ. The compact form of this matrix brings a simple expression for the angular velocity vector of the output axis. Thereafter, an expression for the sphere position is given for the most common types of CVJs. The results section presents the final movement of the system for several cases. Throughout the analysis of the analytical expressions and the resulting angular