Research paper

Contact ratio analysis of the Rzeppa joint based on full-static modeling

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ABSTRACT

Ball-type constant-velocity joints (also known as the Rzeppa ball joints) are widely used for transmitting rotational motion between two misaligned shafts. Due to their geometrical complexity, most methods for analyzing such systems employ a certain degree of simplifying assumptions. In the present study, the problem is formulated with essentially no simplifying assumptions. The concept of the contact ratio commonly used as a performance index of the gear teeth is similarly defined here as the average number of balls actually in contact with the race tracks during power transmission. Many sample cases demonstrate that the contact ratio can be used as a useful performance index for Rzeppa joint systems to estimate the maximum contact force between the balls and tracks. For example, the decrease in the contact force with an increase in the number of balls can be explained in terms of an increase in the contact ratio. The size of the gap between the ball and the tracks was analyzed to explain the asymmetry in the contact force curve.

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1. Introduction

Ball-type constant velocity joints are also known as Rzeppa ball joints and are widely used in mechanical and industrial applications to transmit motion and torque between two misaligned shafts (Fig. 1). A typical Rzeppa joint consists of an inner race, outer race, cage, and set of balls. For structural synthesis of the joint, it is crucial to analyze the contact forces between the components of the system.

Some studies have focused on the kinematic analysis of the homokinetic condition at various joint angles [1–3]. Many other studies analyze the system dynamically for structural synthesis or for analysis of the energy efficiency of the joint [4–6]. In some cases, static analysis was considered as a convenient means for estimating the dynamic behavior of the system [7,8]. Neglecting the inertia of the moving parts in the system, the dynamic behavior of the system can be approximated by the static behavior. Because of the complex geometry and the multiple contacts among the components of the system, it has been considered almost impossible to analyze the joint as it is [9].

A practical way to analyze the system is to use multi-body dynamics software such as ADAMS [10] or DAFUL [11]. In general, such general purpose software is very flexible and can reflect any possible change in the parameters of the system, at least in theory. We can describe the system with a level of detail that is almost as high as 3D CAD models, without any simplifying assumptions. Such flexibility is an important benefit and is widely used in design applications [3,12]. However,
some designers may want more efficient and economically beneficial design tools. In some cases, the system has been reduced to a single-track model with one ball [2–4]. However, it is not possible to determine how the load is distributed among the balls on different tracks. In another example, the trajectory of the balls relative to the race tracks was assumed to be known a priori to reduce the degrees of freedom (DOFs) of the system [7]. A simplified kinematic system was also devised for an approximate analysis of the system [13]. However, the approximations were not validated. Comparative studies with experimental results have been rare [5], and so another means is needed to validate the model.

The objective of this present study is to develop an efficient numerical process for a full-static analysis of a Rzeppa system and apply it to investigate Rzeppa joints with various parameters. For the purpose, we derived a full-static equation and developed an efficient numerical scheme to generate good initial conditions so that the Newton–Raphson method can be successfully applied to solve the static problem. The method was applied to analyze the maximum contact forces between the balls and the tracks, which are the most important factors for the structural synthesis of the joint. The concept of the contact ratio is proposed as a performance index for a Rzeppa joint, which can be used to measure the severity of the contact force arising in the system.

2. Definition of the system

Fig. 1 shows a diagram of a Rzeppa joint. The system is composed of an outer race (OR), inner race (IR), cage, and balls. Each of the races has tracks for the balls. The number of balls (or tracks) $n$ can vary. We will assume 6 balls ($n = 6$) unless otherwise stated. However, the method can be applied for any number of balls. The angle between the input (IR) shaft and output (OR) shaft is denoted $\gamma$ in Fig. 1(a) and represents the articulation angle or the joint angle. The global coordinate system XYZ is defined so that the Z axis is in the direction of the output axis, which is fixed relative to the OR. The angle between the vertical axis X and track 1 (Fig. 1(b)) of OR determines the phase angle $\alpha$ of the system. As shown in Fig. 1(c), the cage has 6 windows, and the balls can contact the four walls of the cage windows.
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