Mechanism and Machine Theory 129 (2018) 36–50

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Research Paper

Dynamic stability of a tripod parallel robotic wrist featuring continuous end-effector rotation used for drill point grinder

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ARTICLE INFO

Article history:
Received 14 January 2018
Revised 4 May 2018
Accepted 23 June 2018

Keywords:
Parallel robotic wrist
Universal joint
Dynamic stability
Continuous end-effector rotation
Vibration

ABSTRACT

This paper deals with the dynamic stability problem of a tripod parallel robotic wrist by means of monodromy matrix method. This robotic wrist can generate a continuous end-effector rotation in any configuration within its orientation workspace, which allows the manipulator to function as a machine tool head used for a drill point grinder. The system's linearized equations of motion are established in terms of both lateral and torsional vibrations to analyze the stability problem, resorting to the Floquet theory. As a result, the stable regions of the manipulator are visualized, and the stability charts are constructed on various parameter planes to detect the parametric instabilities and to reveal the effect of the selected pairs of system parameters onto the stability. Critical parameters, such as the rotating speeds of the driving shaft and the actuation stiffness, are identified for the prototyped grinder.

1. Introduction

Drilling is one of the most important manufacturing processes [1], which accounts for a large portion of the material removal processes. The drill geometry plays a significant role in the drilling operation, as it heavily influences the accuracy of the hole [2,3]. To improve the drilling quality, it is necessary to sharpen the drills, such as the twist or helical typed drills, where a particular drill grinder that produces three-axis motion simultaneously is required. In light of this purpose, a drill point grinder based on a tripod parallel robotic wrist [4], as shown in Fig. 1, was developed for drill point grinding. The focus of this study is the tripod robotic wrist, which pertains to the spherical parallel manipulators (SPMs). This parallel robotic wrist, as depicted in Fig. 1(a), has an asymmetrical architecture, which adopts a universal (U) joint to connect the driving shaft in the center and the end-effector. Besides transmitting the motion/torque, the driving shaft can support the mobile platform to improve the positioning accuracy. Compared to the symmetrical SPM counterparts [5–10], this robotic wrist can generate a continuous end-effector rotation in any configuration. Therefore, this unique characteristics allows the manipulator to function as a machine tool head. For instance, the drill can be fixed to the tool gripper on the end-effector of the wrist, with additional two-axis translations, the grinder can produce the essential movements in the drill grinding process, as shown in Fig. 1(c). On the other hand, the U joint of the wrist suffers from one major problem, namely, it transforms a constant input speed to a periodically fluctuating one, which may induce the vibrations and wear. This paper will investigate the parametric stability problem of the robotic wrist, such as lateral and torsional stabilities.

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https://doi.org/10.1016/j.mechmachtheory.2018.06.020
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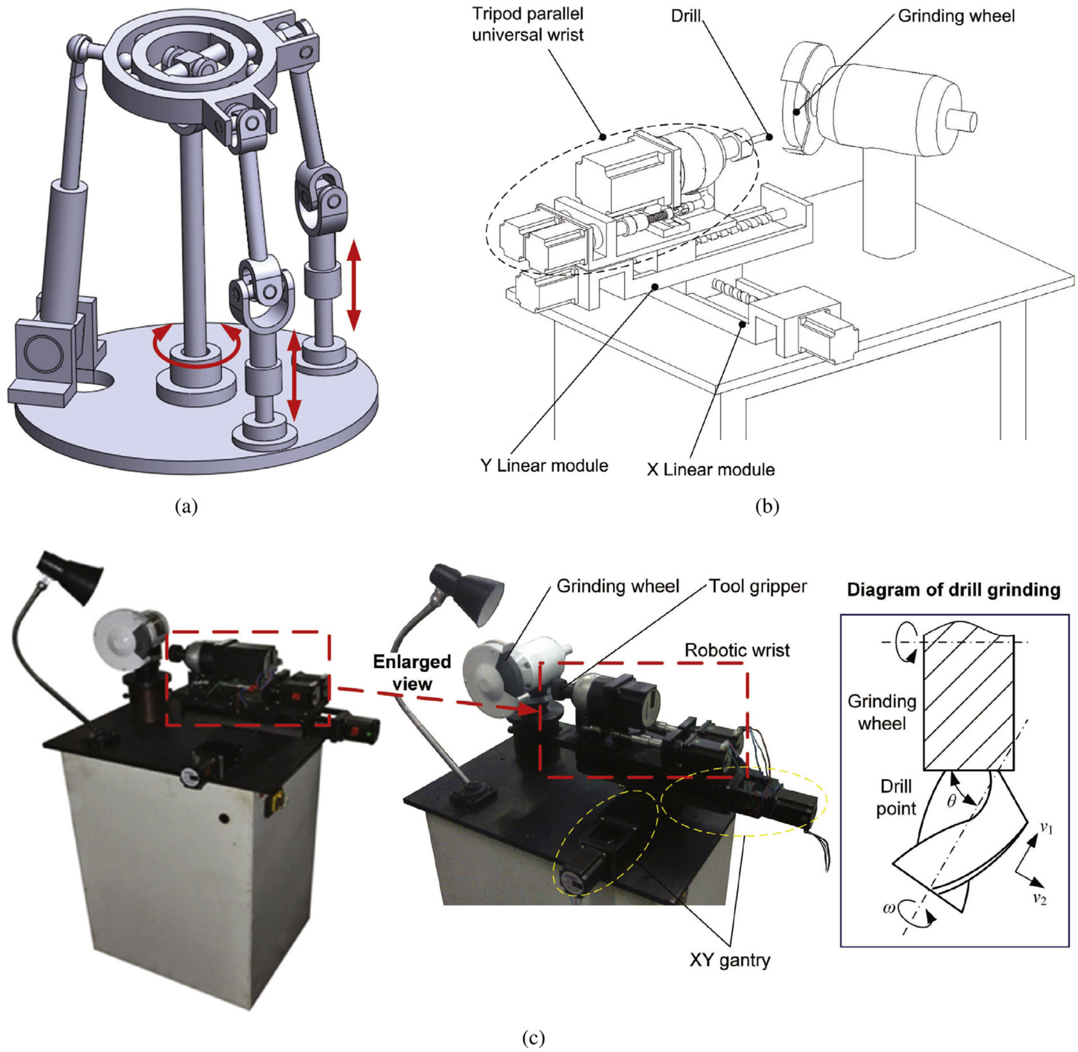

Fig. 1. The drill point grinder based on the tripod parallel universal wrist: (a) wrist mechanism; (b) CAD model; (c) a prototype and the diagram of drill grinding [4].

A number of works on the stability problems of a single or multiple U-joint shaft systems, concerning about the modeling and analysis, can be found in the literature. Early work about the lateral vibrations of a rotating shaft driven by a universal joint can be found in [11,12], wherein the moment applied by the U Joint to the driven shaft was modeled as a non-follower one and the driven shaft was taken to be a massless flexible shaft. In the later work by the same authors, joint friction was taken into account [13]. Double or multiple U joint systems have been studied to analyze the effects of the system parameters [14,15], such as joint angles, viscous friction coefficients, onto the stabilities, without paying attention to the parametric instability. By locating springs and dampers to the end of the driven shaft that is connected to a pinned driving shaft through a U joint, the linearized rigid and flexible parametric equations of motion for the dynamic system were established to investigate the lateral instabilities, where the interdependencies among the parameters of a U-joint mechanism were visualized as well as the parametric unstable regions [16,17]. Similar method has been applied to the shaft system with multiple universal joints [18,19]. On the other hand, for the torsional aspect, it seems that the first model of the U-joint mechanism was a single-degree-of-freedom linearized model [20], and the stability chart was plotted by using the Floquet theory [21]. Later, similar modeling approaches were adopted to derive the nonlinear equations for the torsional stability analysis of U joint [22–27]. Moreover, multi-shaft system consisting of multiple shafts interconnected via Hooke's joints can also be handled using the previous various approaches [28,29]. Based on the lateral and torsional stability analysis, coupled stability problem of the universal joint was studied [30], too. According to the literature, the previous studies focus on single or multiple U-joint mechanisms. On the other hand, a U joint working as transmitting mechanism in a parallel mechanism has not received the attention, which will be the subject in this work. Of the reported works, common approaches to analyze the stability problem of the linear/nonlinear dynamic model of the system include Floquet