Mechanism and Machine Theory 102 (2016) 103–122

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Inverse kinematic and dynamic analysis of planar path generating adjustable mechanism

Gunesh R. Gogate

Independent Researcher, 82/1B/3, 'Malhar', Near Gandhi Training College, Aranyeshwar, Sahakarnagar, Pune 411009, India

ARTICLE INFO

Article history:
Received 12 February 2015
Received in revised form 13 March 2016
Accepted 18 March 2016
Available online 20 April 2016

Keywords:
Adjustable mechanisms
Planar manipulators
Path generation
Inverse kinematics
Inverse dynamics
Singular configurations

ABSTRACT

Path generating adjustable mechanisms with continuous adjustment have been studied in literature, wherein the synthesis has been commonly based on the position kinematics of the mechanism. Many real life applications would, however, demand that the coupler point traces the path at specified velocity and acceleration, thus necessitating development of inverse velocity and acceleration analyses. Further, the inverse dynamic analysis needs to be carried out from the viewpoint of mechanical design and motion control of the mechanism. In this paper, inverse kinematic and dynamic analysis of a path generating four-bar mechanism with continuous one-parameter adjustment is presented. The kinematic analysis is presented for both, the non-singular and singular configurations of the mechanism. Newton's equations of motion are solved by introducing a set of generalized unknowns, resulting in explicit formulae for all the unknowns. The dynamic analysis approach is general and is applicable to any multi-degree-of-freedom single-loop planar mechanism with revolute joints. Results are presented for illustrative examples and future extension of the presented work is discussed.

1. Introduction

Linkage mechanisms are widely used in practice for function, path and motion generation. Although the four-bar mechanism is always the first choice of designers for such applications, it has limitations in terms of the number of precision points or poses that can be satisfied, due to the small number of design parameters. Researchers have proposed use of mechanisms with more than four links, and of adjustable mechanisms with discrete or continuous adjustments, for applications which demand that exact synthesis be carried out for a large number of precision points. This paper is concerned with the inverse kinematic and dynamics of planar path-generating adjustable mechanisms with one-parameter continuous adjustment.

Syntheses of adjustable linkages with discrete or continuous adjustment have been studied by many researchers. In one of the earliest contributions to the field, Tao [1] discussed how the input crank side fixed pivot of a four-bar mechanism could be adjusted to generate variable straight line motion. Adjustments of the fixed pivot were utilized to generate two sets of coupler precision points in [2], and multiple straight-line and L shape paths in [3]. In [4], five-bar loop closure were utilized to synthesize adjustable function-generating four-bars. The concept of Adjustable Robotic Mechanisms was introduced in [5]. Analytical methods of synthesis of such mechanisms were presented, which were in turn based on the synthesis of adjustable dyads. A method to synthesize adjustable four-bar mechanisms which would generate approximate circular arcs with specified radii and tangential velocities was presented in [6], involving a discrete adjustment of the input side fixed pivot. Approaches for optimum synthesis of adjustable four-bar linkages with discrete adjustment of the driven side fixed pivot were presented for approximate generation of multiple continuous paths [7], for multi-phase motion generation [8] and for multi-phase continuous path generation [9]. An

E-mail address: grgogate@gmail.com.

http://dx.doi.org/10.1016/j.mechmachtheory.2016.03.014

approach for two-stage optimum synthesis of adjustable planar crank-rocker mechanisms for generation of multiple specified paths was presented in [10]. A cam-link mechanism was proposed in [11] to generate a specified path precisely, in which a fixed cam was used to continually adjust the length of the side link of the four-bar linkage. Precise generation of continuous paths was achieved by using hybrid cam-linkage mechanisms in [12]. Slider-crank linkages with continuous adjustment of the slider offset were synthesized in [13] to precisely generate desired paths. The relative locations of the joints were adjusted by using cams. In [14], the five-bar, 2-DOF planar mechanism was studied as a continuously adjustable (programmable) function generator. Design considerations such as determinate kinematics, link dimensions, selection of coupler-point and control-input were discussed. The concepts presented in [14] were applied to the case of translating-output seven-bar function generator mechanism in [15]. Optimum synthesis of a function generating adjustable four-bar mechanism, in which the position of the output fixed pivot was continuously adjusted by using an additional revolute link, was presented in [16]. Synthesis of an adjustable four-bar mechanism for path generation was presented in [17]. A slider was added to the four-bar, which would be used to continuously adjust the position of the output fixed pivot. Design of function generating four-bar linkages with variable-length driving link was presented in [18]. A ternary link, a roller link, and a guiding slot in the fixed link were employed to make the length of driving link variable. In [19], optimum synthesis of a path generating adjustable four-bar mechanism with a revolute adjustment was presented, using the method of Differential Evolution. Two new approaches were developed, aimed at improving the slope continuity characteristic of the control parameter. A design method was proposed in [20] for programmable exact path-generators. The proposed 2-DOF adjustable mechanism was driven by a rotary actuator, whereas a linear actuator was used to adjust the effective length of the input link.

It is noted that in [1–20], synthesis is based on considerations of position kinematics. Discrete adjustments are utilized in [1–10], for which velocity and acceleration kinematics and dynamics do not play important role, unlike in case of the approaches which utilize continuous one-parameter adjustment of a four-link mechanism [11–20]. In real-life applications wherein mechanisms with continuous adjustment are intended to be used, it would also be a task requirement that the path points are passed through at specified velocities and accelerations, thus making it necessary that the inverse velocity and acceleration kinematics is taken into consideration. From the viewpoint of mechanical design and motion control of such a mechanism, inverse dynamic analysis needs to be carried out. The inverse velocity and acceleration kinematics and inverse dynamics can also be integrated with the optimum synthesis procedure so that adjustable mechanisms with desirable kinematic, dynamic and control characteristics can be deigned. These observations form the basis of this paper, which takes off from the inverse position analysis based synthesis of the path generating adjustable four-bar mechanism presented in [19], and presents the inverse kinematic and dynamic analyses for the same. It is noted that the input link of the adjustable four-bar studied in [19] undergoes a continuous unidirectional rotation, possibly with varying speed, whereas the adjustment (or control) link undergoes a limited displacement, which is often kept as small as possible. Separate actuators are used to drive the input and adjustment links, and the motion of both needs to be controlled. The inverse kinematic analysis presented here is consistent with the synthesis approach presented in [19] and includes the kinematic analysis at the singular configurations. As far as the inverse dynamic analysis is concerned, Newton's equations of motion are solved utilizing a set of generalized unknowns, resulting in explicit formulae for all the unknowns.

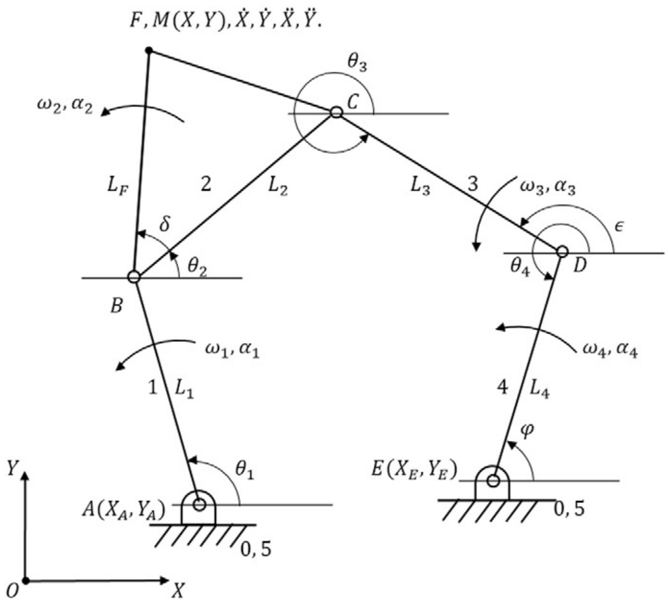

Fig. 1. Kinematic model of the adjustable mechanism.