Mechanism and Machine Theory 118 (2017) 100–114

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Improving the design of high speed mechanisms through multi-level kinematic synthesis, dynamic optimization and velocity profiling

Robert M.C. Rayner[a], M. Necip Sahinkaya[a,*], Ben Hicks[b]

[a] School of Mechanical and Aerospace Engineering, Kingston University, London SW15 3DW, U.K.
[b] Department of Mechanical Engineering, Bristol University, Bristol BS8 1TR, U.K.

ARTICLE INFO

Article history:
Received 30 October 2016
Revised 17 June 2017
Accepted 30 July 2017
Available online 14 August 2017

MSC:
00-01
99-00

Keywords:
Mechanisms
Inverse dynamics
Kinematic synthesis
Velocity cam function
Dynamic performance

ABSTRACT

This paper deals with the fundamental mechanical engineering challenge of mechanism design. While there is a significant body of research associated with mechanism design there are few, if any, approaches that consider kinematic synthesis and optimisation of dynamic performance in an integrated manner. To address this gap, this paper presents a layered (multi-level) design optimisation approach that enables kinematic and dynamic optimisation combined with velocity profiling of the motor/drive system. The approach is presented for both new design and redesign tasks, and is based on the use of inverse kinematic and inverse dynamic analysis, and a novel strategy for generating instantiations of spatial mechanisms that satisfy kinematic quality indicators but with improved dynamic performance. The experimental results validate not only the individual stages of the approach and the models but also the overall improvements achievable through the application of the method. In this regard, the experimental (practical) mechanism exhibited performance improvements in the peak-to-peak torque of 63%, which correlate closely with those predicted theoretically after kinematic and dynamic optimisation. The introduction of a velocity cam function is shown to improve the dynamic quality indicators further and results in an overall reduction in peak-to-peak torque demand of 85%.

© 2017 The Authors. Published by Elsevier Ltd.
This is an open access article under the CC BY license.
(http://creativecommons.org/licenses/by/4.0/)

1. Introduction

The design and optimisation of mechanisms and machines is a fundamental activity of mechanical engineering and has received considerable research attention over the last two decades. To date, much of the extant research has focussed on either the challenges of forward and inverse kinematic design [1,2], forward and inverse dynamic design [3,4], or techniques to enable optimisation with respect to various performance criteria [5–7]. While traditionally it may have been acceptable to consider the kinematic and dynamic response separately, or entirely ignore dynamics during the design process, particularly for low speed duty, this is no longer the case. For todays production environments and machine systems; speed, accuracy and reliability are critically important factors. This demands that mechanisms operate continuously or intermittently at high

---

[*] Corresponding author.
E-mail address: m.sahinkaya@kingston.ac.uk (M.N. Sahinkaya).

http://dx.doi.org/10.1016/j.mechmachtheory.2017.07.022
0094-114X/© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license.
(http://creativecommons.org/licenses/by/4.0/)

Nomenclature

$\mathbf{A}$	Matrix of Lagrangian function coefficients.
$\mathbf{D}$	Vector of $\mathbf{q}$, $\dot{\mathbf{q}}$ and t.
$\mathbf{F}$	Jacobian of constraint equations.
$\mathbf{Q}$	Vector of generalised inputs.
$\mathbf{q}$	Vector of generalised coordinates.
$\boldsymbol{\lambda}$	Vector of Lagrangian multipliers.
a	Coefficients of the Lagrangian function.
C_k	Kinematic cost function.
e_i	Shortest distance between the ith point and the desired orbit.
f	Constraint equations.
i,j	Integers.
L	Lagrangian function.
M	Number of constraint equations.
N	Number of generalised coordinates.
P	Number of points on the orbit.
Q	Generalised inputs.
q	Generalised coordinates.
t	Time.
U	Control input.
W_2	Weighting for the repulsion (control) point.
w_i	Weighting of the ith point.
λ	Lagrangian multiplier.
$(\cdot)^{-1}$	Inverse.
$(\cdot)^{T}$	Transpose.

speeds and do so without compromising their accuracy, without detrimental effect on their life or the life of the transmission and, importantly, without adversely affecting the wider system, e.g. through vibration. It has been shown that even small physical imbalances can induce harmonic content that can compromise performance [8,9]. Such imbalances caused by non-linearities in closed loop chain mechanisms, which become more energetic, the faster a mechanism is actuated. They also imply a direct link between the amount of harmonic content present in an output motion and the peak-to-peak torque magnitude, which a drive motor needs to exert [8]. They also describe methods of modifying the designs of existing mechanisms to reduce the amount of harmonic content present in their output motions by dynamically varying the length of some mechanism links using cams [8] or using smart materials such as piezoelectric stacks [9].

For the aforementioned reasons, it is desirable that both kinematic and dynamic responses are considered concurrently during the early stages of design. Not only should the behaviour of the mechanism be considered but the behaviour its drive system, taking into account parameters such as peak-to-peak torque demands of the drive motor. More specifically, for a spatial mechanism the kinematics and dynamics are interrelated. For example, small changes in the path (locus of motion of the mechanism) and scale (size) require modification of the properties of the mechanism linkages (size, mass and inertia) that can significantly affect the dynamic response, particularly at high speeds. However, their treatment in a unified manner is not straightforward from either a design, modelling formulation or computational perspective [10].

From a design perspective, deciding on mechanism topology, sometimes referred to as type synthesis [11], is arguably the most fundamental decision and will correspondingly limit the potential for dynamic optimisation. Further, in practice, hard constraints on topology will be imposed by machine footprint, internal space and the relative position of other subassemblies, which restricts mechanism topologies/types. Consequentially, to-date, research concerned with minimisation of harmonic content has primarily focussed on redesigning extant mechanisms to be more dynamically balanced. This has included modification of linkage lengths [12] and the addition of masses to linkages [13–15]. Methods exist in which, following the selection of a mechanism design, the kinematic and dynamic behaviour of the mechanism are analysed, considering such parameters as natural frequency as geometric parameters of the mechanism vary [16,17]. Using this information optimal physical parameters can be selected. One such example is proposed in [18] where the contour error of a parallel manipulator is minimised by considering the kinematics and dynamics at an early stage and using this information to switch between control modes as the mechanism is actuated.

From a modelling formulation perspective, there are a number of challenges. If a multi-objective cost function is to be employed, the issue of determining the relative weighting of the components of the cost function, and hence the tradeoff between path accuracy and dynamic performance, must be resolved. Such an approach would necessarily require the designers input, as full automation is not possible due to the distinct situational constraints of each design problem (e.g. physical space, interfaces, kinematic limits and loads). A second, perhaps more important challenge, which also affects the former, concerns the modus operandi of the mechanism models/modelling environments themselves. Many environments

Download English Version:

https://daneshyari.com/en/article/5018797

Download Persian Version:

https://daneshyari.com/article/5018797

Daneshyari.com