Synthesis of Mechanisms Based on their Joint-Forces

Claudio Villegas, RWTH Aachen University, Institute of Mechanism Theory, Machine Dynamics and Robotics, 52074 Aachen, Germany and University of Bio-Bio, Department of Mechanical Engineering, Concepcion, Chile. villegas@igmr.rwth-aachen.de
Mathias Hüsing, RWTH Aachen University, Institute of Mechanism Theory, Machine Dynamics and Robotics, 52074 Aachen, Germany.
Burkhard Corves, RWTH Aachen University, Institute of Mechanism Theory, Machine Dynamics and Robotics, 52074 Aachen, Germany.

Abstract

The design of mechanisms is typically conducted by sequentially following steps intended to [1]:

1. Determine the topology of the kinematic chain underlying the mechanical structure.
2. Define the link geometry based on the task/workspace requirements.
3. Determine the structural dimensioning of links and joints to meet the static loads requirements.
4. Determine the structural dimensioning to include the inertia effects of links, joints and the manipulated object.
5. Determine the elastodynamic dimensioning of the entire structure to ensure its eigenfrequencies avoid the operational speed range.
6. Select the actuators and their mechanical transmissions for the given task.

However, if the dynamic or elastodynamic behavior is unacceptable, then redimensioning is required, which means returning to step three. Moreover, when motors are selected (step 6), a new elastodymanic analysis is necessary. Thus, this process is iterative and sometimes several loops are needed to accomplish an appropriate design. For high-speed machinery, this is specially challenging. High speed increases the nonlinearities, dynamic reaction forces, vibration and wearing [2]. Therefore, considering the dynamic behavior in the first stage of the design would increase the efficiency of the process, by obtaining an earlier dynamic performance estimation.

Several authors have addressed the problem of designing mechanisms with good dynamic behavior from the very beginning of the design process, either by optimization [3, 4] or by layered approaches [5]. Those works use as constraint the dynamic characteristics as the drive torque, the energy consumption, the velocity and/or acceleration of the limbs, but very little attention is paid to reaction forces.

The aforementioned motives induced the authors to start developing a mechanism synthesis method that minimizes the dynamic reaction forces in the joints of the mechanisms (Joint-Forces). The proposed idea defines a first stage, where the synthesis of Function Generator Four-Bar linkages based on the Dead-Center synthesis method [6], with Joint-Forces minimization, was studied parametrically. Based on the auxiliary angle presented in [6], the equations were parametrized for the case when the rocker moves between two positions, the crank rotates with constant angular velocity and the mass and inertia of the links is considered proportional to the link lengths and the squared link lengths, respectively. As objective function was used the peak Joint-Force. It was found that the Maximum Joint-Force function is convex, and hence minimizable. However, one of the difficulties associated to this study is that, in some cases, the resulting optimal design point does not fulfill the classical optimality conditions, lying on a discontinuity of the function derivative (Figure 1). This inconvenient was overcome by using derivative non-dependent resolution methods.

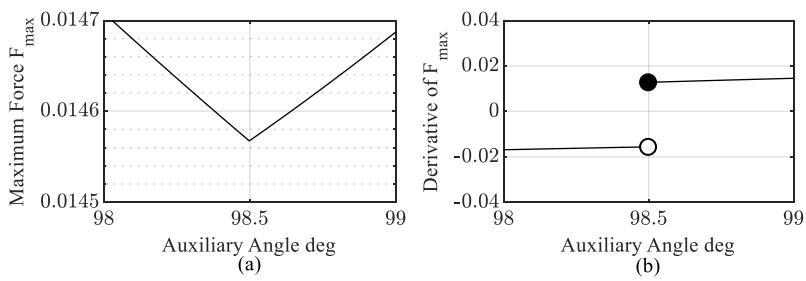

Figure 1. (a) Maximum Joint-Forces as function of the Auxiliary Angle. (b) Derivative of the Maximum Joint-Force with respect to the auxiliary angle.

As an example of the methodology, the synthesis of a Four-Bar linkage that moves a high inertia amount in the rocker between two positions will be exposed. It will also be presented the challenges to extend the method to any four-bar linkage with more than two precision points, and then to other mechanisms with more than four bars or even with more degrees of freedom.

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Villegas Ulloa, Claudio Nabil; Hüsing, Mathias; Corves, Burkhard

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