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Design of planar slider-rocker mechanisms for imposed limit positions, with transmission angle and uniform motion controls

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ABSTRACT

One possible way of converting the displacement of a linear motor into oscillatory motion of an output member is through the use of the planar slider-rocker mechanisms or PRRR in short. In this paper, the optimum synthesis of the PRRR mechanism for prescribed limit positions and best transmission angle characteristics (with and without ensuring uniform input–output motion) is considered. Systematic investigations of the design space in the respective optimization problems reveal some remarkable properties of this mechanism with potential new applications. To assist practicing engineers with selecting the link lengths of a PRRR mechanism, performance charts and parametric design charts are also provided.

1. Introduction

This paper discusses the problem of kinematic synthesizing a PRRR linkage (sometimes symbolized TRRR) for imposed limit positions of the rocker, while simultaneously satisfying good motion transmission characteristics, with or without uniform correlation between the input and output link motions. The only English language work on this subject is [1], which in turn makes reference to German publications [2] and [3]. Note that throughout these publications, a simplifying case is considered where the coupler and rocker have equal lengths. A more recent take on this subject can be found in [4] and [5], with references [6–19] being also relevant to the subject of this paper.

The general PRRR linkage has numerous applications and was studied by a number of researchers in the past. However, the majority of these reports are concerned with the fully rotating *crank-slider* mechanism of the type used in piston compressors, vacuum pumps, sewing machines, and some punch presses. By most accounts, including IFToMM recommendations [20], the term *slider-crank* continues to be used interchangeably, and at times ambiguously, to designate *crank-sliders* (like in piston compressors), *slider-cranks* (like in piston engines), *rocker-sliders* (like in hand pumps), and *slider-rocker* mechanisms (like in some variable pitch propellers, and also the subject of this paper)—see [11–19] for several application examples of this latter category.

The *slider-rocker* mechanism is one of the two inversions of the PRRR kinematic chains with translating input, the other being the *oscillating-slide* also known as *cylinder-incline*, *turning-block*, or *swinging-block* mechanisms [21,22]. The output member (i.e. the rocker) of these mechanisms can be the strut of the landing gear of an aircraft, the steering-knuckle arm of a truck or tractor, a door that opens automatically, a robotic or excavator arm, the blades of a variable pitch propeller, the wicket gates of a water turbine etc.

The synthesis of the PRRR mechanism for given limit positions can be performed graphically as explained in [6,7]. However, satisfying good motion transmitting characteristics is not guaranteed, and a trial-and-error search must be performed until

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acceptable mechanical-advantage or transmission angle properties are satisfied. To avoid overloading the links and joints, it is recommended that the transmission angle (noted μ throughout the paper) remains between 45°and 135°. If gravitational or elastic restoring forces are present, deviations in excess of ±60° from the ideal value of 90° are considered acceptable [23].

Bagci [8] studied the problem of synthesizing *slider-rocker* mechanisms for two prescribed positions of which one is a locking position, but without transmission angle concerns. Plecnik and McCarthy [9] investigated the design of *slider-rocker* mechanisms for function generation, again with no transmission angle control. Farzadpour [11] studied the PRRR mechanism as pitch control for ship propellers, while Koser [10], Moubarak et al. [13,14], Chang et al. [12], and Figliolini and Rea [15] reported on the application of the PRRR *slider-rocker* mechanism in the construction of robotic systems. The investigation of transmission angles in various linkage mechanisms attracted more attention from kinematicians, evident from [23], which refers over one hundred publications on the subject of transmission angle. However, of the 105 references therein, neither deals with the *slider-rocker* mechanism.

The remainder of this paper investigates the capabilities of the PRRR *slider-rocker* to generate, for a given slider displacement, a specified maximum rocker swing while simultaneously ensuring best transmission angle characteristics (***i***) without and (***ii***) with imposing linear correlation between input and output. For case (***i***), the multi-dimensional space of the optimization problem is inspected using *partial-global-minimum* plots [24,25], and some interesting properties are revealed. Furthermore, if there are restrictions upon the possible linear motor placement, the problem can be solved effectively by overlapping such a *partial-global-minimum* plot with the operating space of the mechanism and by observing how these two correlate. Case (***ii***) is formulated as a multi-objective optimization problem that is solved using a modified Normal Boundary Intersection method [26]. To assist practicing engineers with their designs, parametric design charts accompanied by transmission angle, input–output linearity error, and torque-to-force multiplication factor diagrams are also provided in the paper.

2. Synthesis of the PRRR slider-rocker mechanism for prescribed limit positions and optimum transmission angle

Given the *slider-rocker* mechanism in Fig. 1 of link lengths AB, OB, and slider offset y_A, a maximum angular displacement $\Delta\varphi = \varphi_1$-$\varphi_0$ of the rocker is required to be generated for a linear motor displacement S_{max} corresponding to joint A moving between the points of coordinates (x_{As}, y_A) and (x_{Af}, y_A). Without impairing the generality of the approach, the slider displacement is assumed equal to one i.e. $x_{As} - x_{As} = 1$. The dimensions of the real mechanism will be obtained at the end through scaling by a factor equal to the displacement S_{max} of the linear motor utilized.

For the correlated input–output limit positions (x_{As}, φ_s) and (x_{Af}, φ_f) of the mechanism in Fig. 1, the synthesis equations are [4]

$$\begin{aligned} AB^2 &= (x_{As} - x_{Bs})^2 + (y_A - y_{Bs})^2 \\ AB^2 &= (x_{Af} - x_{Bf})^2 + (y_A - y_{Bf})^2, \end{aligned} \tag{1}$$

which are equivalent to

$$\begin{aligned} AB^2 &= x_{As}^2 - 2OB \cdot (x_{As}\cos\varphi_s + y_A \sin\varphi_s) + OB^2 + y_A^2 \\ AB^2 &= x_{Af}^2 - 2OB \cdot (x_{Af}\cos\varphi_f + y_A \sin\varphi_f) + OB^2 + y_A^2. \end{aligned} \tag{2}$$

After subtracting Eq. (2) and then substituting $x_{Af} = x_{As} - 1$ and $\varphi_f = \varphi_s + \Delta\varphi$, the normalized length of the rocker results as

$$OB = \frac{x_{As} - 0.5}{x_{As}\cos\varphi_s - (x_{As} - 1)\cdot\cos(\varphi_s + \Delta\varphi) + y_A[\sin\varphi_s - \sin(\varphi_s + \Delta\varphi)]} \tag{3}$$

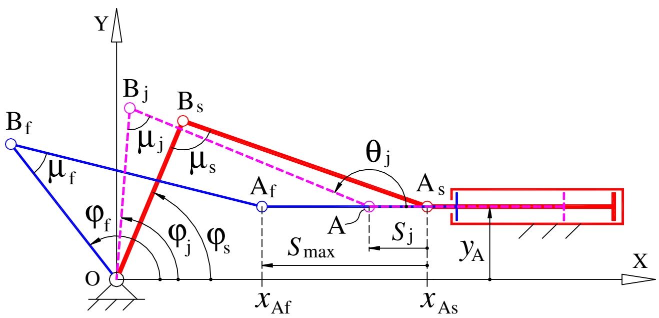

Fig. 1. PRRR mechanism actuated by a linear motor with a maximum stroke S_{max} shown in its start "s" and finish "f" positions, and in an intermediate position "j" corresponding to a current slider displacement S_j.