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Nomogram-based Synthesis of Planar Mechanisms, Part II: Six Bar-One Slider Mechanism

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Abstract
The objective of this paper is to present a second application on using nomogram-based synthesize for a 6 bar – 1 slider planar mechanism. The new technique does not require the solution of the nonlinear kinematic equation or the application of optimization technique. A nomogram is constructed using four of the kinematic functions of planar mechanisms through which the mechanism can be synthesized for a desired time ratio and stroke of the mechanism. The effectiveness of the technique is investigated using an example of a mechanism synthesis for a 2.2 time ratio and an 0.2 normalized stroke.

Keywords –*Planar mechanism synthesis, Six bar-one slider mechanism, Synthesis using nomogram-based procedure.*

I. INTRODUCTION

Nomogram-based synthesis is invented by the author and applied to a number of planar mechanism to investigate the effectiveness of the approach by studying complex planar mechanisms. This is the second research paper in this aspect hoping facilitating planar mechanism synthesis for practicing mechanical engineers.

Stumph (2000) presented the theory developed for the analysis and design of mechanical press mechanisms and a MATLAB-based SDAMP software [1]. Shiakolar, Koladiya and Kebrle (2005) presented a methodology combining differential evolution , evolutionary optimization ang geometric centroid of precision positions technique for mechanism synthesis. They applied their methodology to the synthesis of six bar linkages for dwell and dual dwell mechanisms with prescribed timing and transmission angle constraints [2]. Dong and Wang (2007) presented an approach for optimal synthesis of six bar dwell mechanisms. They adapted the combination of global and local searching to satisfy the prospective accuracy. They presented examples showing the efficiency and accuracy of their technique [3]. Wilhelm and Van de Ven (2011) designed a variable displacement six bar crank-rocker-slider mechanism for a hydraulic pump/motor with high efficiency at low displacement. They analysed the mechanism performance in terms of transmission angles, slider stroke, mechanism footprint and time ratio [4].

Sedano, Sancibrian, de Juan, Viadero and Egana (2012) proposed a dynamical and optimal synthesis presented a hybrid optimization approach for the synthesis of linkages. They tested the proposed method using two examples, one of them was a six bar die-cast injection machine [5]. Wang (2013) presented a technique for synthesizing established kinematics model of the six bar drawing mechanism by bar-group method and produced simulated system by Visual Basic. The optimization results showed that the kinematic performance was improved greatly [6]. Hassaan (2014) formulated the synthesis problem of a six bar planar linkage in the form of an objective function and three functional constraints. He optimally synthesized the six bar planar linkage for a single dwell across 60 degrees of the crank rotation with maximum error less than 0.23 % [7].

Almandeel, Murray, Myszka and Sumph (2015) proposed a topology based on a symmetric 5 bar presented a modification to the function generation synthesis methodology revealing a continuum of defect-free slider-crank solutions for four precision points. They allowed the specification of velocity and acceleration at the precision points [8]. Hassaan (2015) presented a new technique for the synthesis of complex planar mechanisms using nomogram-based synthesis. He outlined a procedure of five steps and applied it to the synthesis of a xix bar – two sliders mechanism for time ratio up to 4.3 and normalized stroke up to 3.33 [9].

II. MECHANISM

This mechanism was studied before by the author to investigate its optimal synthesis [10]. The line diagram of the mechanism is shown in Fig.1. It consists of a 4-bar linkage OABQ and a second coupler BC driving the output slider at C on a vertical guide going through the fixed joint Q. The mechanism has a unit degree of freedom with crank OA as an input having complete rotation if the dimensions of the 4-bar linkage generates a Grashof's crank-rocker one [10].

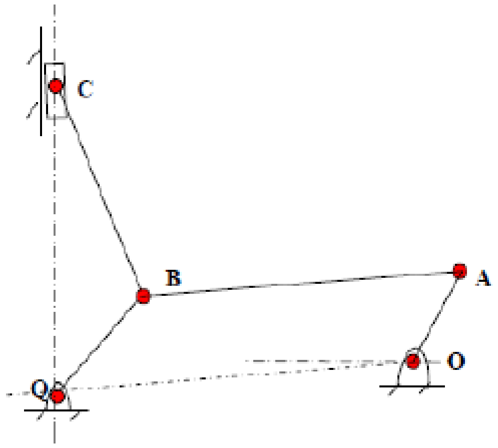

Fig.1 The 6 bar-1 slider mechanism [10].

III. MECHANISM ANALYSIS

In order to investigate the stroke and time ratio of the mechanism, it is drawn in its two limiting positions. Fig.2 shows the 6 bar – 1 slider mechanism in one of its limiting positions when the output slider is in its highest position at C_1. The mechanism analysis is as performed by the author in a previous work [10].

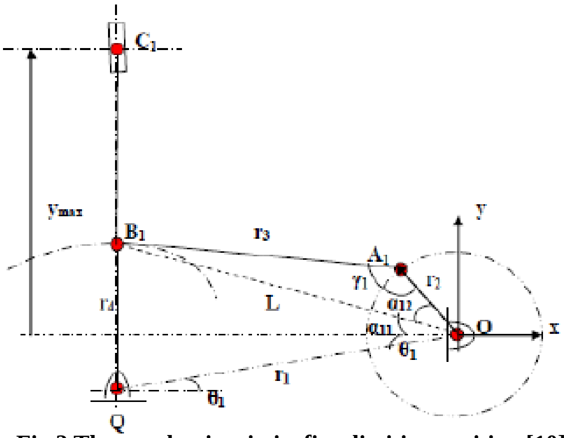

Fig.2 The mechanism in its first limiting position [10].

Using Fig.2, the maximum slider position relative to the fixed frame of reference Oxy, y_{max} is given by:

$$y_{max} = r_4 + r_5 - r_1\sin\theta_1 \qquad (1)$$

The lowest position of the slider with dimension y_{min} from Q is obtained from the limiting position of the 4 bar linkage OABQ as shown in Fig.3.

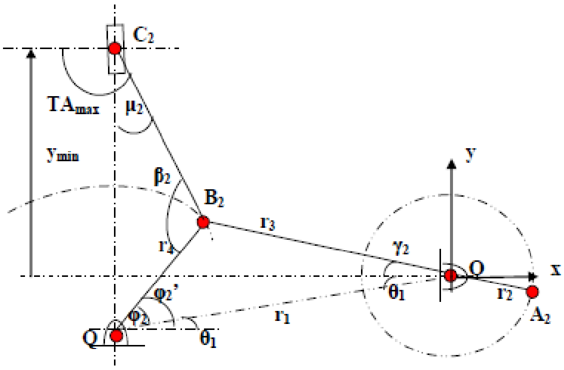

Fig.3 The mechanism with slider in its lower limiting position.

The lowest slider position with dimension y_{min} is obtained as follows using Fig.4:

Angle μ_2:

$$\mu_2 = \sin^{-1}\{(r_4/r_5)\sin(90 - \varphi_2')\}$$

where: $\varphi_2' = \varphi_2 + \theta_1$

$$\varphi_2 = \cos^{-1}\{[r_1^2 + r_4^2 - (r_3-r_2)^2] / (2r_1r_4)\}$$

Angle β_2:

$$\beta_2 = 180 - \mu_2 - (90 - \varphi_2')$$

$$y_{min} = (r_4\sin\beta_2 / \sin\mu_2) - r_1\sin\theta_1 \qquad (2)$$

Using Eqs.1 and, the slider stroke is:

$$S = y_{max} - y_{min} \qquad (3)$$

Mechanism time ratio:

In Fig.3:

$$\alpha_2 + \theta_1 = \cos^{-1}\{[r_1^2 + (r_3-r_2)^2 - r_4^2] / [2r_1(r_3-r_2)]\} \qquad (4)$$

In Fig.2:

$$L = \sqrt{\{(r_4 - r_1\sin\theta_1)^2 + (r_1\cos\theta_1)^2\}}$$

$$\alpha_{11} = \sin^{-1}\{(r_4-r_1\sin\theta_1) / L\}$$

$$\gamma_1 = \cos^{-1}\{(r_2^2 + r_3^2 - L^2) / (2r_2r_3)\}$$

$$\alpha_{12} = \sin^{-1}\{(r_3\sin\gamma_1) / L\}$$

Now: $\alpha_3 = \alpha_{11} + \alpha_{12}$ (5)

The crank angle between the two positions corresponding to the lowest and upper position of the slider defining its stroke, Θ is:

$$\Theta = 180 - \alpha_3 + \alpha_2 \qquad (6)$$

Where α_2 and α_3 are given respectively by Eqs.4 and 5.

The time ratio of the mechanism, TR is given by:

$$TR = (360 - \Theta) / \Theta \qquad (7)$$

Mechanism minimum and maximum transmission angles:

The minimum and maximum transmission angles of the mechanism occur at the mechanism positions corresponding to the limiting positions of the 4 bar linkage OABQ. Fig.4 shows the mechanism in its second limiting position corresponding to the 4 bar linkage OABQ.

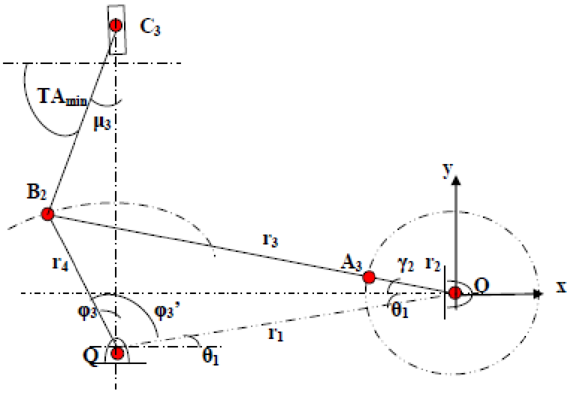

Fig.4 The mechanism in the second limiting position of the 4 bar linkage OABQ.

Angle φ_3':

$$\varphi_3' = \cos^{-1}\{[r_1^2 + r_4^2 - (r_3 + r_2)^2] / (2r_1r_4)\}$$

Angle φ_3:

$$\varphi_3 = \varphi_3' - (90 - \theta_1)$$

Angle μ_3:

$$\mu_3 = \sin^{-1}\{(r_4/r_5) \sin \varphi_3\}$$

The minimum transmission angle, TA_{min} is (Fig.4):

$$TA_{min} = 90 - \mu_3 \qquad (8)$$

Using Fig.3, the maximum transmission angle TA_{max} is:

$$TA_{max} = 90 + \mu_2 \qquad (9)$$

IV. PARAMETRIC EFFECT ON PERFORMANCE PARAMETERS

According to the research work in [..], normalized dimensions are changed in the ranges: $1.78 \le r_{1n} \le 1.9487$, $1.93 \le r_{3n} \le 4.92$, $1.10 \le r_{4n} \le 3.98$ and $8.43 \le r_{5n} \le 10$. The normalized ground has little variation about its mean. It has a mean value of 1.8656 with 0.0698 standard deviation. Therefore, r_{1n} is kept constant at 1.8656. The coupler BC of normalized dimension r_{5n} is kept constant at a level of 10.

The effect of the 4-bar coupler dimension r3n and rocker dimension r4n on the whole mechanism performance is shown in the following figures:

Time ratio, TR: Fig.5.

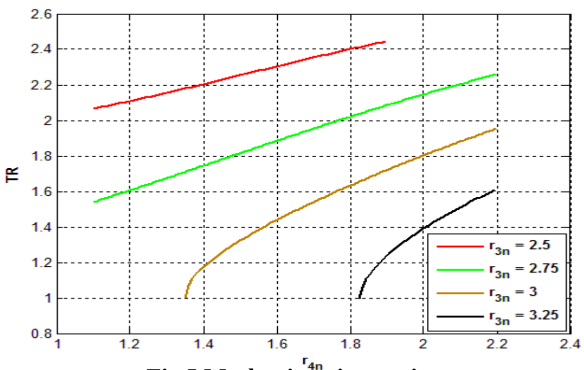

Fig.5 Mechanism time ratio.

Normalized stroke, S_n: Fig.6.

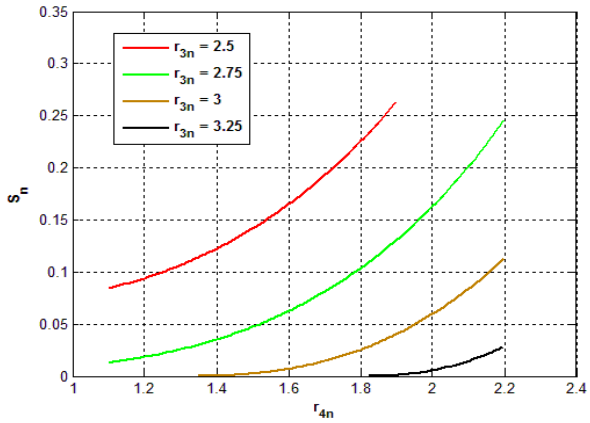

Fig.6 Mechanism normalized stroke.

The performance of the synthesized mechanism is judged by its transmission angle. It has not to decrease than 45 degrees nor increase than 135 degrees [11]. The effect of the mechanism normalized dimensions r3n and r4n is shown below:

Minimum transmission angle, TA_{min}: Fig.7.

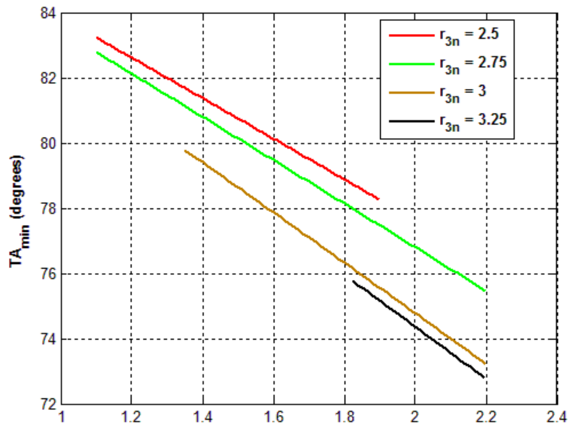

Fig.6 Mechanism minimum transmission angle.

Maximum transmission angle, TA_{max}: Fig.7.

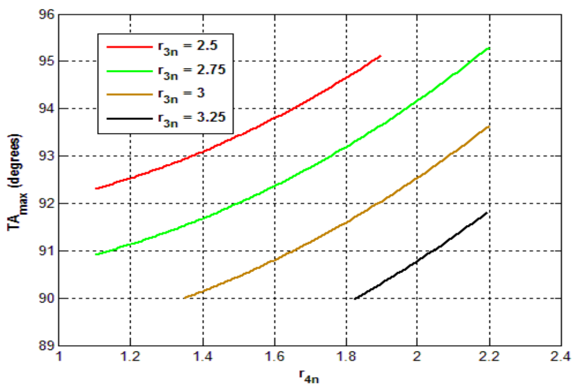

Fig.7 Mechanism maximum transmission angle.

V. SYNTHESIS NOMOGRAM

A synthesis nomogram is constructed from the four figures of the time ratio, stroke , minimum transmission angle and maximum transmission angle of the mechanism under study [9]. For the 6 bar – 1 slider mechanism presented in this paper, the synthesis nomogram is given in Fig.8.

VI. SYNTHESIS USING THE NOMOGRAM

The author suggested a synthesis procedure consisting of five steps [9]. The input of the synthesis process is a desired time ratio and normalized stroke. Suppose that it is required to synthesize a 6 bar – 1 slider mechanism such that the time ratio is 2.2 and the normalized stroke is 0.2. We proceed as follows:

1. Draw a horizontal line in the TR graph of the nomogram at TR = 2.2. This line intersects the r_{3n} curves of r_{3n} = 2.5 and r_{3n} = 2.75 in two values for r_{4n} which are 1.4 and 2.08.
2. Looking at the S_n graph of the nomogram at the combinations (r_{3n}=2.5 , r_{4n}=1.4) and ((r_{3n}=2.75 , r_{4n}=2.08). The first combination gives S_n = 0.125 and the second combination gives S_n = 0.2. The second combination reveals the desired normalized stroke. Therefore, the mechanism normalized dimensions are:
   - Ground link: r_{1n} = 1.8656
   - First coupler link: r_{3n} = 2.75
   - Rocker link: r_{4n} = 2.08
   - Second coupler link: r_{5n} = 10.00
3. The performance of the synthesized mechanism is checked through the assignment of the minimum and maximum transmission angles.
4. Going down from r4n = 2.08 of the TR graph by a line to intersect the green curve of TA_{min} at r_{3n} = 2.75 locates the minimum transmission angle as TA_{min} = 76.0 degrees.
5. Now, going down from the r_{4n} = 2.08 on the S_n graph to intersect the green curve of TA_{max} at r_{3n} = 2.75 locates the maximum transmission angle as TA_{max} = 95.7 degrees.
6. This is considered as a successful mechanism synthesis since it reveals the mechanism dimensions for the specified time ratio and stroke and fulfilling the constraints on the transmission angle.

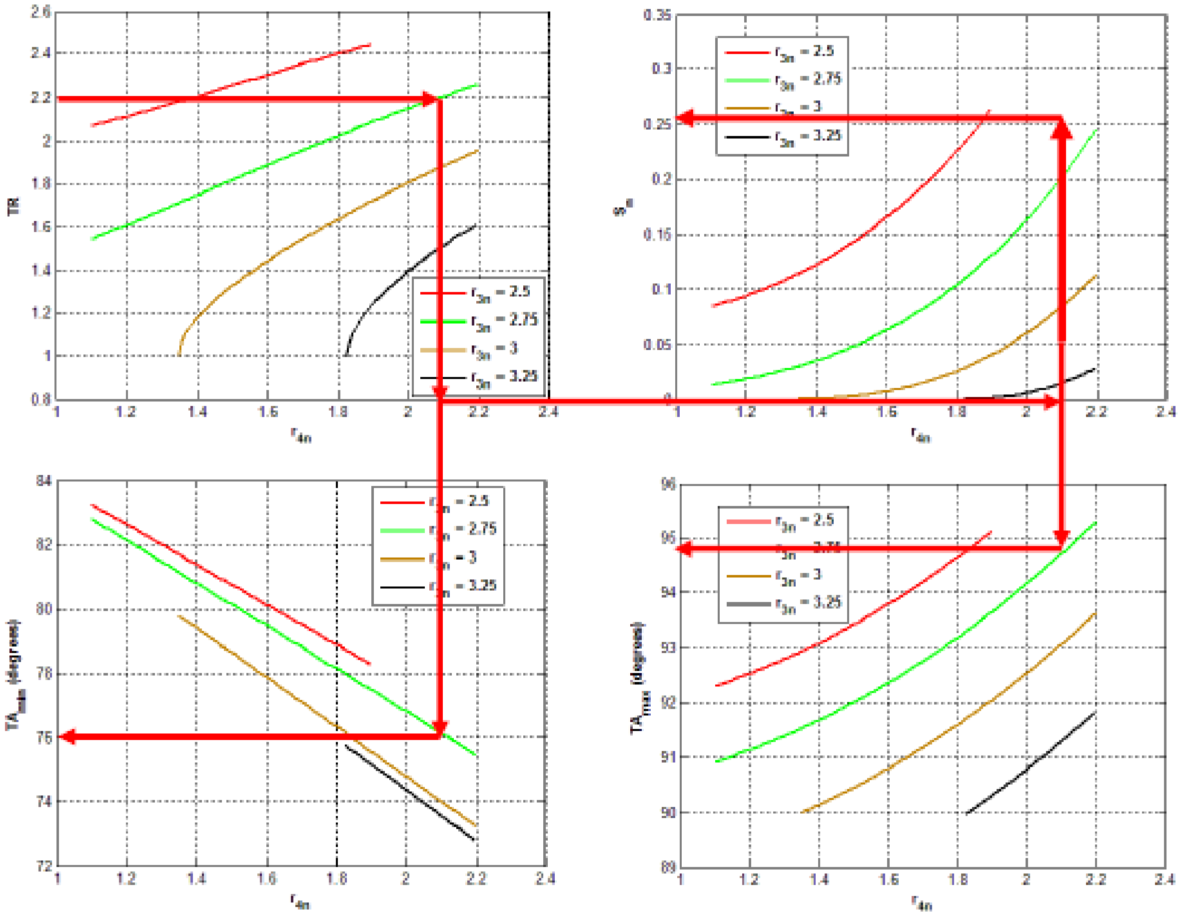

Fig.8 Synthesis nomogram.

VII. CONCLUSION

- A second application on nomogram-based synthesis was presented in this work.
- The synthesis of a 6 bar – 1 slider planar mechanism was considered without need to solve nonlinear equations or apply advanced optimization techniques.
- Two of the mechanism normalized dimensions were fixed at specific levels assigned based on previous work by the author.
- The effect of the 4-bar linkage coupler and rocker normalized dimensions on the kinematics characteristics of the 6 bar mechanism was investigated.
- A nomogram was designed consisting of four charts for mechanism time ratio, stroke, minimum transmission angle and maximum transmission angle.
- The idea of using the nomogram in mechanism synthesis was explored through the requirement of synthesizing a 6 bar – 1 slider mechanism for a time ratio of 2.2 and a normalized stroke of 0.2.
- The nomogram-based synthesis provides the normalized dimensions of the mechanism and the corresponding time ration, normalized stroke, minimum transmission angle and maximum transmission angle.
- The transmission angle of the mechanism was within the recommended range for accepted performance of the synthesized mechanism.

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