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Synthesis of Planar Mechanisms, Part VIII: Five Bar Mechanism

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Abstract:
The objective of this paper is to synthesize a 5 bar planar mechanism through investigating the effect of its dimensions on its performance functions. The analysis shows that it is possible to a time ratio as large as 3, a normalized stroke as large as 1.57. The minimum transmission can be adjusted not to go below 45^o and the maximum transmission angle not to exceed 135^o. The paper provides synthesis monograms helping the machine designer to select the mechanism dimensions for any desired requirements (time ratio and stroke) such that the transmission angle does not violate its boundaries.

Keywords –*Planar mechanism synthesis, Five bar mechanism, Synthesis without optimization, Synthesis charts.*

I. INTRODUCTION

Planar mechanisms have wide application in mechanical engineering. It is well known that five bar mechanisms with all R-joints have two degree of freedom except gear five bar ones. In the present work another configuration of five bar linkage having unit degree of freedom is studied to examine the possible range of its stroke and time ratio for accepted range of its transmission angle.

Cannor, Douglas and Gilmartin (1995) presented a methodology for the synthesis of MDOF mechanisms using genetic algorithms. They used the error between the actual path and the desired path as an objective function [1]. Cannor, Douglas and Gilmartin (1998) reviewed several uses of harmonic information in the synthesis of mechanisms. They applied their approach to a five bar mechanism having two DOF. They claimed that the inclusion of harmonic information into the objective function locates high quality solution [2]. Blackett (2001) presented a technique for the optimal synthesis of planar five link mechanisms producing a desired mechanical advantage over a specified path. His research showed a potential application which was the design of strength machines [3]. Ouyang, Li and Zhang (2003) described an integrated approach to design a real time controllable mechanism considering force balancing and trajectory tracking. They considered (for for illustration purpose) a two DOF five bar mechanism driven by two servomotors and its links had arbitrary mass distribution [4].

He and Lu (2005) proposed a dynamical and optimal synthesis method for parallel mechanisms based on the dynamical configuration technique. They studied the problem of optimizing the kinematics isotropy of a five planar parallel mechanism [5]. Mussa, Russel and Sodhi (2006) presented a technique for synthesizing adjustable planar five bar motion generator to approximate prescribed rigid body positions and satisfy rigid body positions with prescribed tolerances. They considered a two-phase moving pivol adjustments in the plane 5 bar motion generator [6]. Mundo, Gatt and Dooner (2007) proposed the integration of five bar linkage with noncircular gears to synthesize a precise path generating mechanism. They analysed two case studies to illustrate their synthesis procedure [7].

Ouyang, Zhang and Gupta (2008) proposed a topology based on a symmetric 5 bar structure for displacement amplification. A compliant mechanism was implemented for the amplification. They conducted experiments to give validation of their theoretical analysis [8]. Rao (2013) presented an analytical method to synthesize a variable crank-rocker and drag-linkage planar type five bar mechanism with transmission angle control. He considered the synthesis of a five bar mechanism motion for two separate positions [9].

Ye, Fang and Guo (2014) presented the idea of constructing reconfigurable limits by integrating metamorphic linkages as sub-chains. They have given the degree of freedom of the reconfigurable parallel mechanism in different configurations with the metamorphic linkages in different phases. They addressed the actuation scheme for this kind of mechanisms [10].

II. MECHANISM

The five bar mechanism under study is used by Ballaney in his book “Theory of Machines” [11]. The mechanism is shown in Fig.1. It has a driving crank OA, Oscillating L-shaped lever pivoted at O_2, a slider at the end of the crank joined to the crank and slides inside the oscillating lever. The lever drives a vertical rack through a half gear with centre at O_2 as a rigid part with the lever. The mechanism has 5 links, 3 R joints, 2 P joints and 1 G joint. It has a unit degree of freedom.

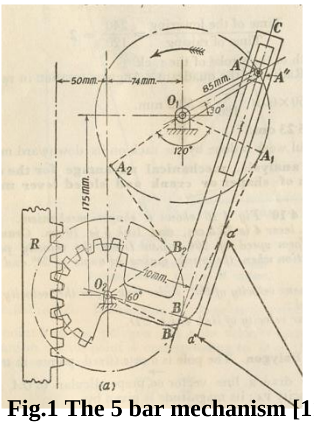

Fig.1 The 5 bar mechanism [11].

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 a line diagram of the 5 bar mechanism in one of its limiting positions when the output rack is in its highest position.

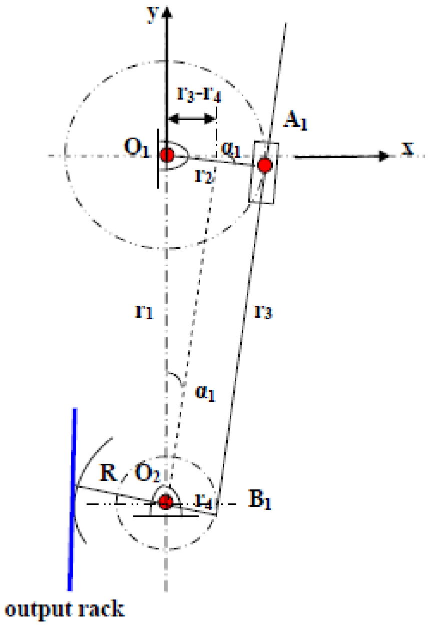

Fig.2 The mechanism in its first limiting position.

Mechanism time ratio:

In the limiting position of Fig.2, the crank OA makes an angle α_1 with the x-direction of the frame of reference. From the geometry in Fig.2, the crank angle α_1 is given by:

$$\alpha_1 = \sin^{-1}\{(r_2 - r_4)/r_1\} \quad (1)$$

Normalizing the mechanism dimensions relative to the crank length r2 yields:

$$r_{1n} = r_1/r_2$$
$$r_{3n} = r_3/r_2$$
$$r_{4n} = r_4/r_2$$

Using the normalized dimensions, Eq.1 becomes:

$$\alpha_1 = \sin^{-1}\{(1 - r_{4n})/r_{1n}\} \quad (2)$$

The second limiting position of the mechanism is shown in Fig.3.

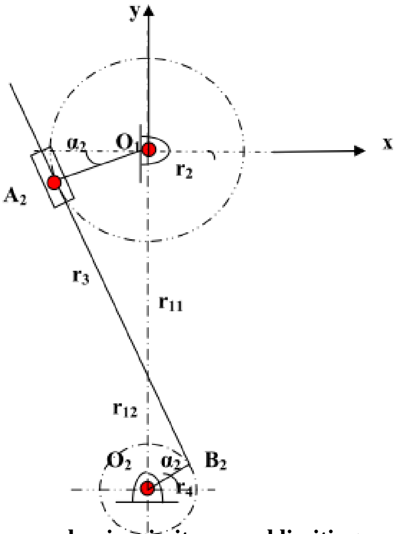

Fig.3 The mechanism in its second limiting position.

The crank orientation angle α_2 with the horizontal direction is given as:

$$\alpha_2 = 90 - \cos^{-1}\{(r_2 + r_4)/r_1\} \quad (3)$$

Using the normalized dimensions r1n and r4n, Eq.3 becomes:

$$\alpha_2 = 90 - \cos^{-1}\{(1 + r_{4n})/r_{1n}\} \quad (4)$$

Now, the crank angle between the crank positions corresponding to the mechanism limiting positions Θ is:

$$\Theta = 360 - (\alpha_1 + \alpha_2) \quad (5)$$

The time ratio TR of the mechanism is therefore,

$$TR = (360 - \Theta) / \Theta \quad (6)$$

Mechanism stroke:

As shown in Figs.2 and 3, the output is taken from the oscillating lever through a pinion sector and rack transforming the motion from being an angular motion of the oscillating lever to a translation motion of the rack.

The normalized stroke of the output rack corresponding to the two limiting positions of the mechanism, S_n is given by:

$$S_n = R_n(\alpha_2 + \alpha_1) \quad (7)$$

Where R_n is the normalized radius of the pinion sector (R/r_2).

Minimum and maximum transmission angles:

Neglecting the effect of the pressure angle between the rack and pinion sector, the optimal direction of the reaction force from the pinion sector on the rack is the vertical direction producing the maximum driving torque , i.e. 90 degree with the r4 centerline By this definition, referring to figs.2 and 3, the minimum and maximum transmission angles are given by:

$$TA_{min} = 90 - \alpha_1 \qquad (8)$$

And $$TA_{max} = 90 + \alpha_2 \qquad (9)$$

IV. PARAMETRIC EFFECT ON PERFORMANCE PARAMETERS

The normalized dimensions are changed in the ranges: $2 \le r_{1n} \le 5$ and $0.25 \le r_{4n} \le 1$. R_n (R/r_2) of the pinion sector is fixed at a unit value. The effect of r1n on the performance parameters of the mechanism for r4n =1 is given in Table 1.

Table 1: Effect of r_{1n} on the performance parameters of the mechanism.

r_{1n}	TR	S_n	TA_{min} (degrees)	TA_{max} (degrees)
2	3	1.57	90	180
2.25	2.07	1.095	90	152.7
2.5	1.8376	0.9273	90	143.13
3	1.6051	0.7297	90	131.81
3.5	1.4802	0.6082	90	124.85
4	1.40	0.5236	90	120
4.5	1.3436	0.4606	90	116.39
5	1.3015	0.4115	90	113.58

The effect of both r_{1n} and r_{4n} on the mechanism time ratio is shown in Fig.4.

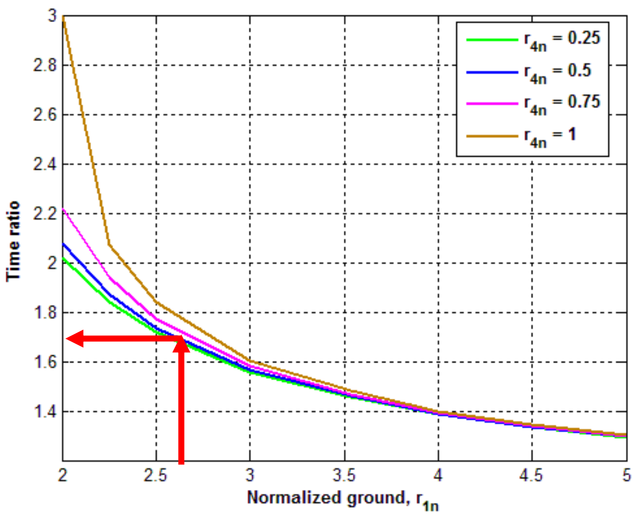

Fig.4 Effect of r_{1n} and r_{4n} on the time ratio of the mechanism.

The effect of both r_{1n} and r_{4n} on the mechanism dimensionless stroke is shown in Fig.5.

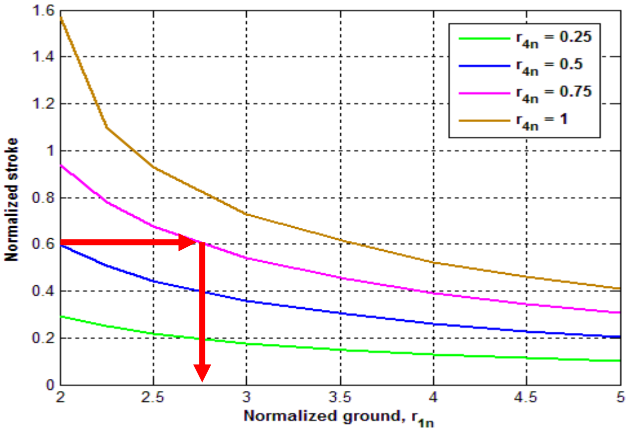

Fig.5 Effect of r_{1n} and r_{4n} on the stroke of the mechanism.

The effect of both r_{1n} and r_{4n} on the mechanism minimum transmission angle is shown in Fig.6.

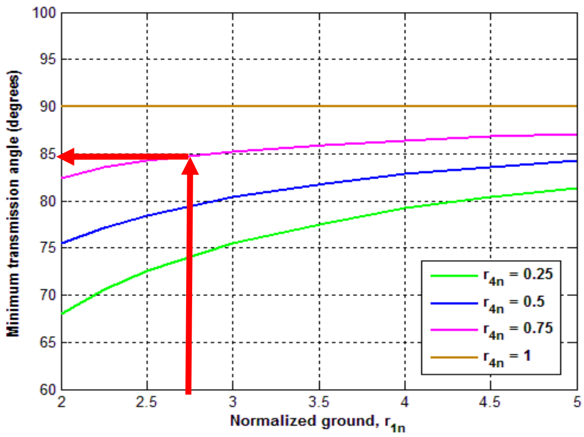

Fig.6 Effect of r_{1n} and r_{4n} on the minimum transmission angle of the mechanism.

The effect of both r_{1n} and r_{4n} on the mechanism maximum transmission angle is shown in Fig.7.

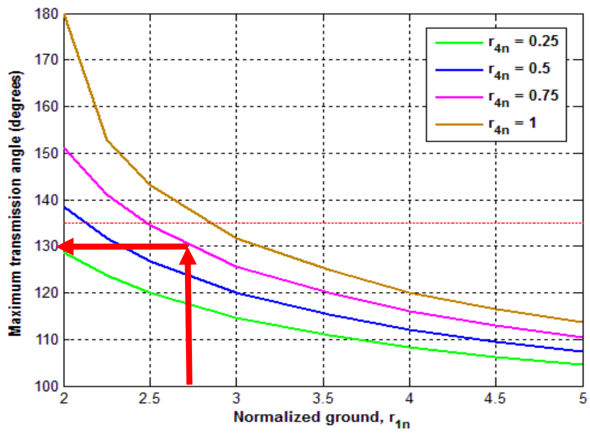

Fig.7 Effect of r_{1n} and r_{4n} on the maximum transmission angle of the mechanism.

A rid line is drawn at the boundary level of 135 degrees to help is selecting r1n and r4n not to avoid this limit [12].

V. SYNTHESIS NOMOGRAMS

The four figures (Fig.4 through 7) can be used as nomograms for mechanism synthesis as follows::

1. The normalized ground r_{1n} and the normalized rocker r_{4n} are selected from Fig.7 for a maximum transmission angle < 135 degrees (small levels of r_{4n} are preferred while large levels of r_{1n} are preferred).
2. Any selected levels are safe regarding the minimum transmission angle since the values are > 45 degrees.
3. The desired stroke is set on Fig.5 giving both r_{1n} and r_{4n}. Suppose that it is required to have a 5 bar mechanism proving 0.5 normalized stroke, then a horizontal line from 0.6 in Fig.5 locates the two normalized dimensions of the mechanism as r_{1n} = 2.75 and r_{4n} = 0.75.
4. In Fig.4, a vertical line at r_{1n} = 2.75 up to the curve for r_{4n} = 0.75, then a horizontal line locates the time ratio as 1.66.
5. In Fig.6, a vertical line at r_{1n} = 2.75 up to the curve for r_{4n} = 0.75, then a horizontal line locates the minimum transmission angle as 85 degrees
6. In Fig.7, a vertical line at r_{1n} = 2.75 up to the curve for r_{4n} = 0.75, then a horizontal line locates the maximum transmission angle as 130 degrees.

VI. CONCLUSION

- A new five bar mechanism used by Ballaney [11] was synthesized.
- A new synthesis technique based on graphical nomograms was presented.
- It was possible to go with mechanism time ratio to about 3.
- Normalized stroke from 0.1 to 1.57 was possible.
- The minimum transmission angle was in the range from 68 to 90 degrees which is above the boundary limit of 45 degrees [12].
- The maximum transmission angle was from 104.5 to 180 degrees violating the boundary limit of 135 degrees. Through proper selection of r1n and r4n it was possible to select a proper maximum transmission angle.

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