Matlab- Based Graphical Synthesis of Planar Mechanisms Synthesis of a 4-Bar Quick Return Mechanism

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ABSTRACT

Graphical synthesis using MATLAB for a four bar quick return mechanism is a successful approach that will help in designing a mechanism and satisfy all the needed characteristics of the mechanism. The quick return mechanism has wide industrial applications like the shaping machine.

This paper discusses the mathematical model of the four bar mechanism, also it shows the analytical equations used to design the mechanism. MATLAB was used to solve a set of equations and give the optimal dimensions of the planar mechanism.

***Keywords*:** *Mechanism design, four bar linkage, quick return.*

1. INTRODUCTION

Four-bar quick return mechanism is the simplest form of a sliding mechanism, Mechanism synthesis techniques range from simple graphical techniques going through analytical approaches with many assumptions and trials to sophisticated techniques using optimization application.

The subject of mechanism synthesis was a great interest for most of the researchers for several past years. The following survey mentions some publications for the last 15 years and it was written by referring to our professor's papers – Prof. Galal A. Hassaan, [1]

- Russel (2001) presented several methods for synthesizing adjustable spatial mechanisms. He synthesized spatial 4 and 5-bar mechanisms for different phases of prescribed rigid body positions. He extended his approach to incorporate rigid body tolerance problems [2].
- Cabrera, Simon and Prado (2002) used a searching procedure applying genetic algorithms to the problem of synthesis of 4-bar planar mechanisms. They outlined the possibility of extending their method to other mechanisms [3].
- Smaili and Zeineddine (2003) presented a software package based on Simulink and Matlab for the synthesis and analysis of linkage mechanisms. They coded precision point synthesis methods and optimization synthesis techniques to yield a mechanism for a specific task [4].
- Bultovic and Djordjevic (2004) studied the optimal synthesis of a 4-bar linkage by method of controlled deviation. They used the Hooke-Jeeves optimization technique without dependence on the initial selection of the projected variables [5].
- Shiakolas, Koladiya and Kebrle (2005) presented a methodology combining different evolution, an evolutionary optimization and geometric control of precision positions for mechanism synthesis. They employed two penalty functions, one for constraint violation and one for relative accuracy [6].
- Damangir, Jafarijashemi, Mamduhi and Zohoor (2006) proposed a curvature path description method for path generation of planar mechanisms. The objective function was independent of rotation and translation transformations [7].
- Xi and Chen (2007) proposed an approach for the kinematic synthesis of a crank-rocker mechanism to generate a coupler motion passing through a prescribed set of positions [8].
- Schrocker, Juttler and Agner (2008) presented an evolution based method for optimal mechanism synthesis. They used curve and surface evolution techniques from computer-aided design and image processing [9].
- Al-Smadi (2009) calculated the mechanism parameters required to achieve a set of prescribed rigid body positions [10].
- Peng (2010) developed an optimal synthesis method based on link length structural error for the kinematic synthesis of adjustable planar mechanisms. He developed the optimal synthesis method for adjustable planar 4-bar mechanisms for three typical synthesis tasks [11].
- Mutawe, Al-Smadi and Sodhi (2011) discussed the path generation of 4-bar mechanism with position tolerance variations due to joint running tolerance [12].
- Hwang and Wang (2012) presented a synthesis technique for the planar Watt-I six-bar mechanism with a coupler point passing through 3 or 4 acceleration poles. They provided examples to illustrate the feasibility of their proposed method [13].

- Larochelle (2013) presented a dimensional synthesis technique for solving the mixed exact and approximate motion synthesis problem for planar RR kinematic chains. His algorithm did not require the use of any optimization algorithm [14].
- Kamat, Hoshing, Pawar, Lokhande, Patankar and Hatawalane (2014) synthesized an adjustable planar 4-bar mechanism for different angles. They adjusted the length of different links to obtain different paths accurately [15].
- Shete and Kulkarni (2015) used genetic algorithm to achieve a desired trajectory. They analyzed three problems having different curvature [16].

1.1 FOUR BAR MECHANISM

Planar four-bar mechanism is made of four links connected in a loop by four one degree of freedom joint. The joints may differ from a mechanism to another, they might be revolute, hinged, or prismatic joints.The first link connected to the ground is called Crank, the other link connected to the ground is called Rocker, and the link between the Crank and the Rocker is called Coupler as shown below in Fig.1

D.O.F. = 3x(n-1) – (2xR)

Where;n = number of links

R= number of revolute joints

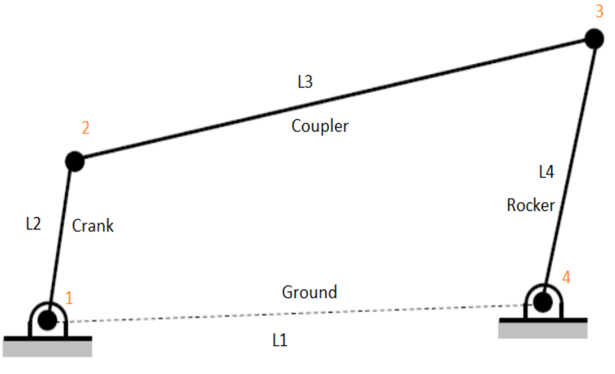


Fig.1 Links of Four Bar Mechanism

D.O.F =

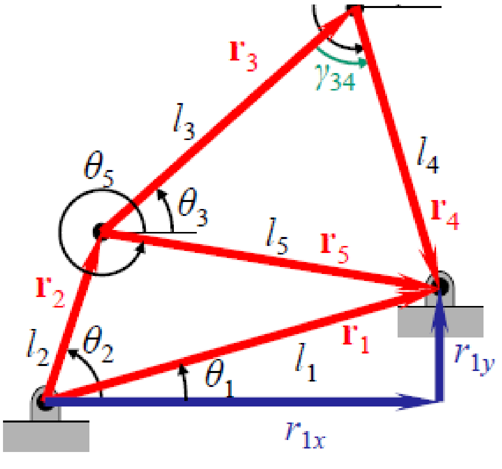
3x(4-1) – (2x4) = 1 – one degree of freedom

2. ANGULAR AND POSITION ANALYSIS OF A 4-BAR MECHANISM

As it appears below in Fig.2,

- L_1 is the ground length (known)
- L_2 is the crank length (known)
- L_3 is the coupler length (known)
- L_4 is the rocker length (known)
- θ_1 is the ground angle (known)
- θ_2 is the crank angle (known)
- θ_3 is the coupler angle (unknown)
- θ_4 is the rocker angle (unknown)

Fig.2 Analysis of Four bar Mechanism Chain



2.1. ANALYZING THE LOOPS TO GET THE ANGLES AND POSITIONS OF ALL THE LINKS

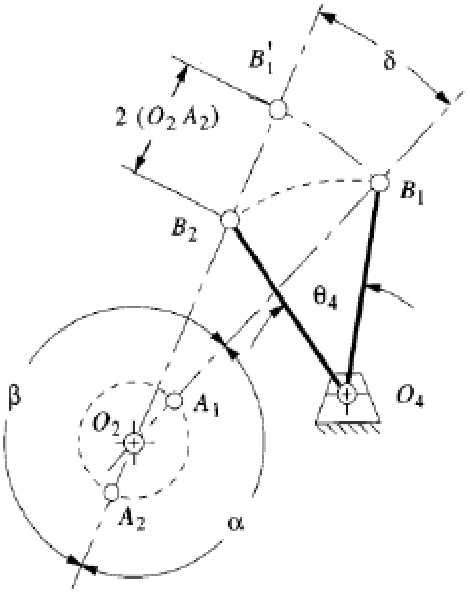
- $\theta_5 = \tan^{-1}\left[\frac{(L_1*\sin(\theta_1)-L_2*\sin(\theta_2))}{L_1*\cos(\theta_1)-L_2*\cos(\theta_2)}\right]$
- $L_5 = \frac{(L_1*\sin(\theta_1)-L_2*\sin(\theta_2))}{\sin(\theta_5)}$(an imaginary line)
- $\theta_3 = \cos^{-1}\left[\frac{{L_3}^2+{L_5}^2-{L_4}^2}{2*L_3*L_5}\right] + \theta_5$
- $\theta_4 = \cos^{-1}\left[\frac{(-L_5*\cos(\theta_5)-L_3*\cos(\theta_3))}{L_4}\right]$
- Transmission angle: $\gamma_{34} = \theta_4 - \theta_3 - 180^o$

3. DESIGN PROCEDURE OF A QUICK RETURN FOUR BAR MECHANISM

Graphical synthesis of mechanisms is an easy, and a nearly reliable method of designing a mechanism with a special purpose, that gives a certain output. Although the error range can sometimes be unacceptable, the graphical synthesis offers an easy and quick way to form a mechanism. There are many mechanisms that can be synthesized using graphical methods, one of which is the 4-bar quick return mechanism. Stated below the design procedure of a

4-bar quick return mechanism according to the book "Design of Machinary, 5th edition" by Robert Norton [17].

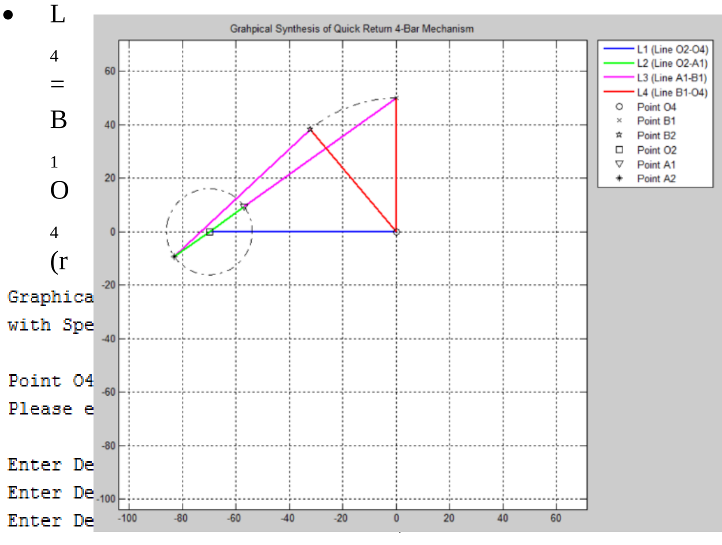
- For crank angle α and β, the time ratio is: $TR=\frac{\beta}{\alpha}$, such that $\beta > \alpha$
- $\alpha + \beta = 360°$
- Define the angle δ such that: $\delta = |180 - \alpha| = |180 - \beta|$
- Note that this design procedure is limited for time ratios up to 1.5



- Select a point O_4, and draw the required length of link 4 (rocker)
- Draw the other position of link 4 (rocker) with the required stroke angle in-between
- Mark the ends of link 4 by B_1 and B_2
- Draw a line (line1) from B_1 at any convenient angle
- Draw another line (line2) from B_2 at an angle of δ from line 1
- The intersection of line1 and line2 in point O_2 (the origin of the crank)
- Draw a circle around O2 with radius equals $0.5 * B_1 B_2$
- Half the length of the line connecting B_1 and B_2 is the length of the crank

Fig.4 Graphical Synthesis of 4-bar Quick Return Mechanism at T.R. =1 and Stroke = 40°

- A_1 and A_2 indicates the angular position of the crank at both the rocker position
- $L_1 = O_2 O_4$ (ground)
- $L_2 = O_2 A_1$ (crank)
- $L_3 = A_1 B_1$ (coupler)
- $L_4 = B_1 O_4$ (rocker)



- It is important the lengths of the linkage follows Grashof condition

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Enter Angle of Rocker @ minimum position (degrees): 90
Enter X-position of O2: -70
Enter Y-position of O2: 0
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- L_2 has to be the smallest link so that the linkage would be a crank rocker linkage
- It is important that the transmission angle "μ" of the mechanism lies within the accepted range ($45° < \gamma < 135°$)

4. CASE STUDIES

4.1 GRAPHICAL SYNTHESIS OF A QUICK RETURN 4-BAR WITH TIME RATIO 1, ROCKER LENGTH 50MM, AND ROCKER STROKE IS 40°

a) Enter the required date:

b) Enter assumed data:

c) Obtained results:

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Analysis of Quick Return 4-Bar Mechanism

L1 = 70.000 mm
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Fig.3Four-bar quick return linkage

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)84 mm
L3 = 69.759 mm
L4 = 50.000 mm
Stroke = 39.954 degrees
Time Ratio = 1.114
Maximum Transmission = 90.362 degrees
Minimum Transmission = 50.264 degrees

Since (S+L)<(P+Q) & S=L2
Therefore, Crank Rocker Grashof Mechanism
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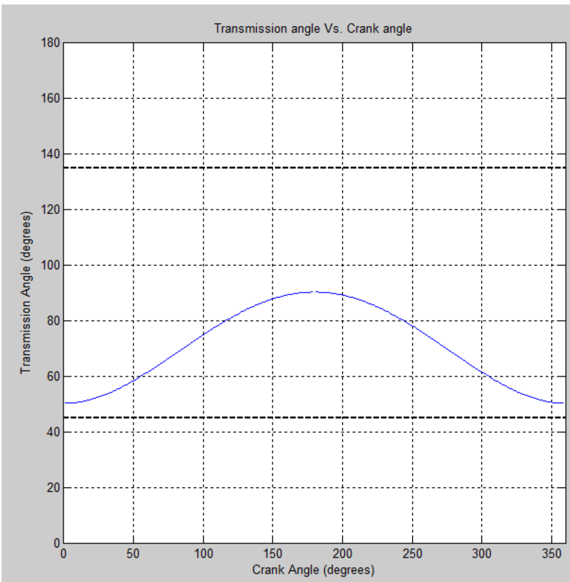

Fig.5 Transmission Angle curve with Crank Angle for T.R =1 and stroke=40°

4.2 GRAPHICAL SYNTHESIS OF A QUICK RETURN 4-Bar WITH TIME RATIO 1.15, ROCKER LENGTH 50 MM, AND ROCKER STROKE 40°

a) Enter the required date:

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Graphical Synthesis of a Quick Return 4-bar Mechanism
with Specific Stroke and Time Ratio

Point O4 is set @ (0,0)
Please enter the following data

Enter Desired Time Ratio: 1.15
Enter Desired Stroke (degrees): 40
Enter Desired Rocker Length (mm): 50
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b) Enter assumed data:

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Enter Angle of Rocker @ minimum position (degrees): 90
Enter X-position of O2: -70
Enter Y-position of O2: 0
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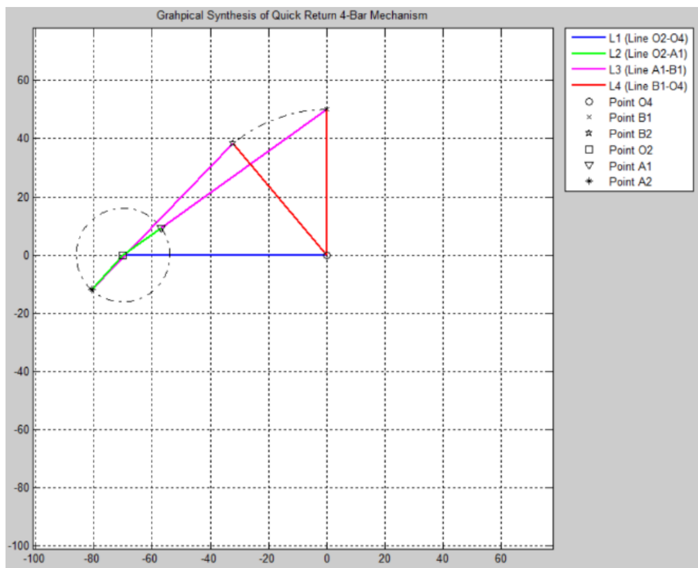
c) Obtained results:



4.3 RETURN 4-BAR WITHTIME RATIO 1.25, ROCKER LENGTH 50MM, AND ROCKER STROKE 40°

a) Enter the required date:

```
Point O4 is set @ (0,0)
Please enter the following data

Enter Desired Time Ratio: 1.25
Enter Desired Stroke (degrees): 40
Enter Desired Rocker Length (mm): 50
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b) Enter assumed data

```
Enter Angle of Rocker @ minimum position (degrees): 90
Enter X-position of O2: -70
Enter Y-position of O2: 0
```

Fig.7Transmission Angle curve with Crank Angle for T.R =1.15 and stroke=40°

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Ana

L1
L2
L3
L4
Str
Tim
Max
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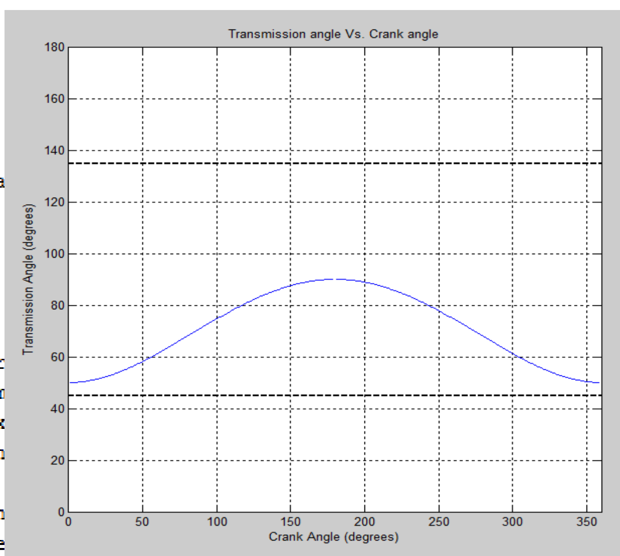

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c) Obtained results:

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Analysis of Quick Return 4-Bar Mechanism

L1 = 70.000 mm
L2 = 16.084 mm
L3 = 69.743 mm
L4 = 50.000 mm
Stroke = 39.950 degrees
Time Ratio = 1.114
Maximum Transmission = 90.380 degrees
Minimum Transmission = 50.277 degrees

Since (S+L)<(P+Q) & S=L2
Therefore, Crank Rocker Grashof Mechanism
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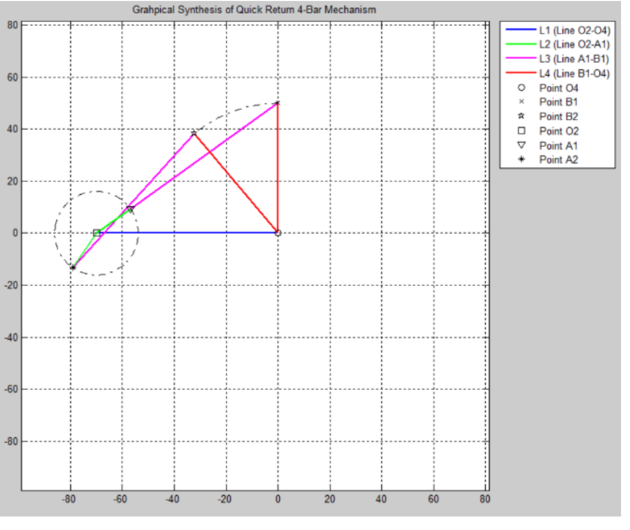

Fig.8Graphical Synthesis of 4-bar Quick Return Mechanism at T.R. = 1.25 and Stroke = 40^o

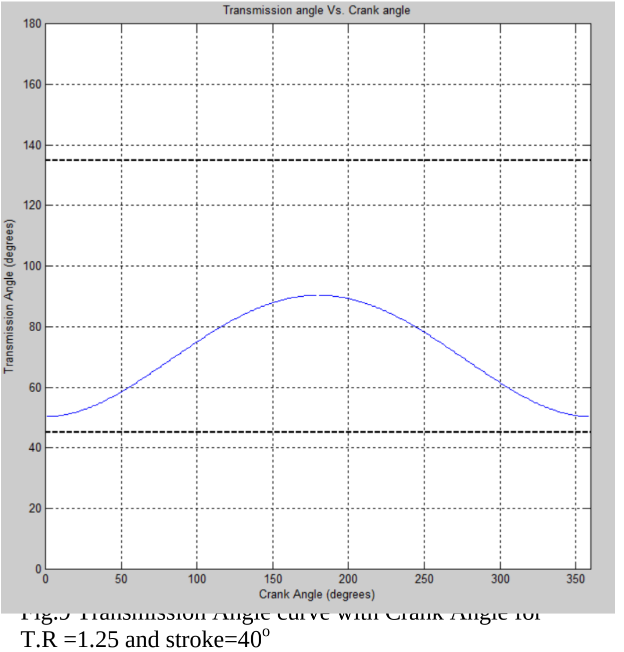

Fig.9 Transmission Angle curve with Crank Angle for T.R =1.25 and stroke=40^o

5. Conclusion

In this paper, we used MATLAB based graphical design to form a four-bar quick return linkage. It was important to have the design in the recommended range by which we mean that the transmission angle lies within the recommended design range. To do so, we had to use the graphical design procedure for synthesizing a four-bar quick return linkage then we had to perform a vector analysis to calculate the position and angle for each link in the four-bar linkage and accordingly calculate the transmission angle as the crank rotates.

The use of graphical based design to synthesize a linkage is not very accurate, however, it can provide a very close and reliable results. Also, it must be noted that there are many lengths and position assumptions for the graphical based design which can change the results if the assumptions were altered.

We included three examples as case studies in the paper. The first example was of a time ratio unity; meaning that the linkage isn't of a quick return nature, then we increased the time ratio to 1.15, and finally to 1.25. Generally, the results were accepted as the transmission angle for each example lied within the accepted range.

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