Simulation Model for Coupler Curve Generation using Five Bar Planar Mechanism With Rotation Constraint

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Abstract: **In the simulation of planar five bar mechanism, the objective is to calculate the positions of all the links which are rigid bodies. The planar five bar mechanism has second degree of freedom. There can be two input links. By adding a new constraint to conventional five bar motion generation model, the degree of freedom is reduced to one. This five bar constrained mechanism generates a family of curves. The simulation model allows the user to actually input the mechanism and generate the motion curve. The model indicates the locking positions and user can modify the dimensions.**

Keywords: Five Bar Planar mechanism, Coupler curve, Constraints, Motion Generation

I. INTRODUCTION

1.1 Motion Curve Generation

The coupler curve generation is related to the dimensions of the mechanism and the constraints. In the synthesis of mechanism, we are given some positions which are to be achieved by the mechanism to be designed. In some situations we are given three or four positions of a link which must be achieved. In this simulation, the entire motion curve will be given and the mechanism should generate the same motion curve for some point on its linkage. The simulation software is designed in such a way that the user can chose the mechanism dimensions and orientation which will generate a similar curve from the library.

The simulation software also allows the user to design a five bar mechanism of any dimension and orientation, and the software will test it during simulation. The generated curve is simulated if the mechanism does not come across locking situation. The user will be allowed to change dimensions, positions as well as orientation. The velocity of the desired point is also calculated and graphed.

When the motion curve is given, user is required to get the five bar mechanism from the library to generate the similar curve as close as possible. The simulation software will calculate the dimensions for the five bar mechanism, which will generate the given curve within the tolerance limit.

1.2 Literature Survey

As a survey, different papers were referred and studied. In this area of five bar planar mechanisms, Balli and Chand [1] introduced many methods for motion generation. In addition they have also elaborated method for synthesizing five bar mechanisms by using transmission angle control. Wang and Yen [3] have discussed the precise approach for synthesizing with five prescribed precision positions. Basu and Farhang [4] introduced a mathematical formulation for the approximate analysis and design of two input, small crank five bar mechanisms for function generation. Lin and Chang[5] modified pole method for synthesis planar, geared five bar function generators. Ge and Chen[6] introduced software based method for path synthesis. The authors have also given the effect of the ling length, cranck angles and gear tooth ratio on the motion of geared five bar linkage. Cheng and Trang[7] explained the web based mechanism and analysis of five geared planar synthesis. Some authors have designed mechanical automata. In the first stage the motion approximation on the input sequence is done in relation with the geometric and motion constraints of mechanical parts. In stage two they generate the layout by solving sizing parameters and spatial layout of all the elements. So by referring all these, we are developing a Simulation Model for Coupler Curve Generation using Five Bar Planar Mechanism with Rotation Constraint. In which, the model will allow the user to actually input the mechanism and generate the motion curve.

1.3 Related Work

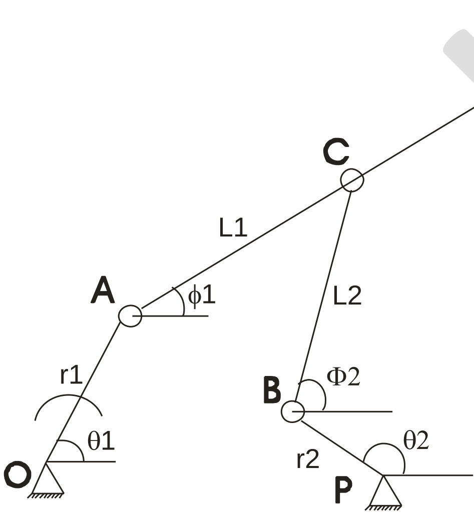
For analysis and design of mechanisms, computer software can be used. This fact was recognized in the earlier days of computers.[Freudenstein 1954].The approaches used by the software systems can be different, it can be function oriented implementation or shape oriented implementation. The relation among the positions will be represented as nodes on the graph. In several design methods, a specified input motion is transformed into output motion. Chiou and Sridhar [1999] used a library of mechanisms. These are used as basic building blocks along with symbolic matrices which represented the library. The system decomposes an intended function into simple functions so that the match will be found in the library. A mechanism can be selected from the parameterized set as per the prior knowledge of the motion. Zhu et al.[2012]. This approach can handle linear, ellipsoidal or circular motions. In this work, we are using a sampling based approach which generates a representative set of motions using a five bar mechanism.

1.4 Motivation and Scope of work

In conventional motion generation method, user can calculate the mechanism dimensions to achieve the required set of the link positions. Two or three link orientations will be given and we can design the remaining links of the four bar mechanism. These methods will not assure about the entire motion curve. In this work, the entire motion curve of a point is given to us. Hence the conventional method can not be used. The five bar mechanism has degree of freedom as two. It allows us to adjust the speed and directions of the two input links. This will generate a wide variety of curves, which do not have any mathematical equation. We restrict our scope for the input links rotating in opposite directions with same angular speeds. Here a constraint is incorporated in the five bar mechanism to reduce the degree of freedom to one. There will be two input links. The constraint is provided in such a way that both the input links rotate with same angular velocity, either in same direction or opposite direction.

II. MATHEMATICAL DISCUSSION FIVE BAR PLANAR MECHANISM

2.1 Complex Number approach



Terminology:

OP is fixed link.
OA and PB are input links.
$\theta 1$ and $\theta 2$ are initial orientation angles of links OA and PB respectively.
$\phi 1$ and $\phi 2$ are angles made by links AC and BC
r1 and r2 are lengths of input links OA and PB.
L1 and L2 are lengths of auxiliary links AC and BC.
$\omega 1$ and $\omega 2$ are angular velocities of OA and PB such that $\omega 1 = -\omega 2$

$OA = a = r_1 e^{j\theta 1}$ …. (i)
$OP = p$ …. (ii)
$b = p + r_2 e^{j\theta 2}$ …. (iii)
$c = a + AC = a + L_1 e^{j\phi 1}$ .... (iv)
Also $c = b + BC = b + L_2 e^{j\phi 2}$ …. (v)

Equating c from (iv) and (v)

$$a + L_1 e^{j\phi 1} = b + L_2 e^{j\phi 2}$$
$$r_1 e^{j\theta 1} + L_1 e^{j\phi 1} = p + r_2 e^{j\theta 2} + L_2 e^{j\phi 2}$$

Equating real and imaginary parts

$$r_1 \cos(\theta_1) + L_1 \cos(\phi_1) = p + r_2 \cos(\theta_2) + L_2 \cos(\phi_2)$$
$$r_1 \sin(\theta_1) + L_1 \sin(\phi_1) = r_2 \sin(\theta_2) + L_2 \sin(\phi_2)$$

For the given mechanism r_1, r_2, L_1, L_2, p, θ_1, θ_2 are all known. The only unknowns are ϕ_1 and ϕ_2.
Hence we get simultaneous equations as

$$L_1 \cos(\phi_1) - L_2 \cos(\phi_2) = \alpha$$
$$L_1 \sin(\phi_1) - L_2 \sin(\phi_2) = \beta$$

Solving we get

$$\cos(\phi_2) = (-Q + sqrt(Q*Q - 4 P*R))/ (2*P)$$

where

$\alpha = -r_1 \cos(\theta_1) + p + r_2 \cos(\theta_2)$
$\beta = -r_1 \sin(\theta_1) + r_2 \sin(\theta_2)$
$\chi = (L_1*L_1 - L_2*L_2 - \alpha*\alpha + \beta*\beta)/(2*L_2)$
$P = \beta*\beta - \alpha*\alpha$
$Q = 2*\alpha*\chi$
$R = \beta*\beta - \chi*\chi$

For the existence of solution

$$Q*Q - 4*P*R > 0$$

And numerically

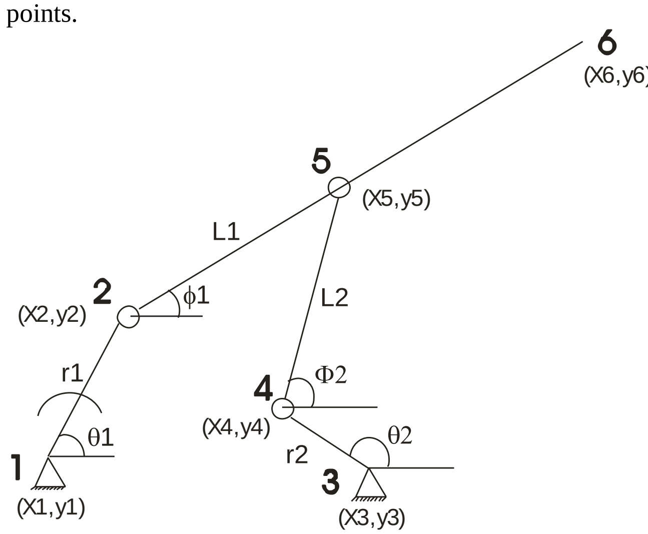
$$| -Q + sqrt(Q*Q - 4 P R) | < |2 P|$$

Which results in basic condition that

$$L_2 > L_1 \text{ and some more.}$$

2.2 Constant length geometrical approach

While designing the mathematical model, we use the constant length approach to find the coordinates of the points.



We know (x1,y1) and (x3,y3)
Using angles at any moment as θ1 and θ2
We can find (x2,y2) and (x4,y4) as

$x2 - x1 = r1 \cos(\theta 1) \quad y2 - y1 = r1 \sin(\theta 1)$

$x4 - x3 = r2 \cos(\theta 2) \quad y4 - y3 = r2 \sin(\theta 2)$

Circles with centers 2 and 4 having radii L1 and L2, will intersect at point 5.

$(x - x2)^2 + (y - y2)^2 = L1^2$

$(x - x4)^2 + (y - y4)^2 = L2^2$

Solving these two equations for x and y
We come across following steps

$2(x - x2)\, k1 = k2 + 2\, y\, k3$

Where $k1 = x2 - x4$

$k2 = (L2 - L1)^2 - k1^2 + y2^2 - y4^2$

$k3 = y2 - y4$

finally the quadratic equation

$a1\, y^2 + b1\, y + c1 = 0$

where $a1 = (k3/k1)^2 + 1$

$b1 = (k2/k1)(k3/k1) - y2$

$c1 = (k2/2\,k1)^2 - L1^2 + y2^2$

The further conditions will be

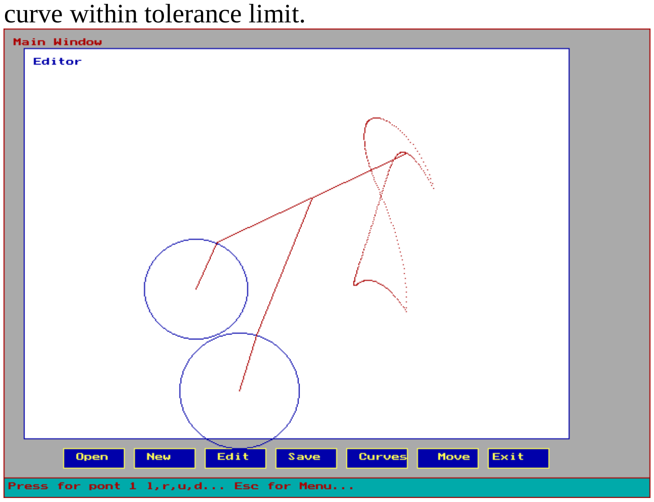
$b1^2 - 4\, a1\, c1 > 0$ … necessary to get real value of y.

This condition is similar to the condition we got in the previous approach.

III. SIMULATION TOOL

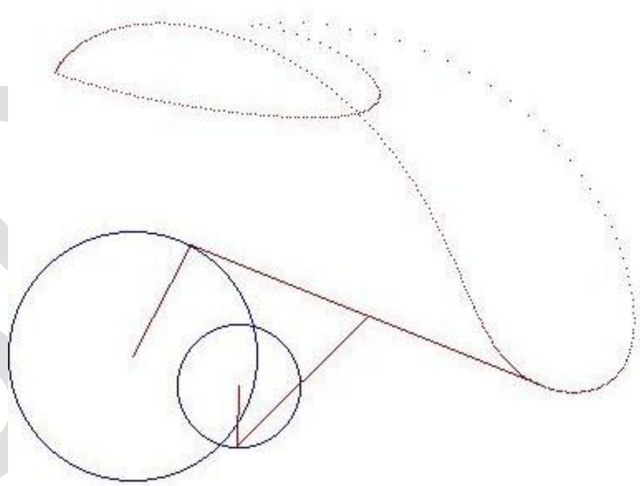
The simulation tool for the planar five bar mechanism is developed using C language with graphic programming. It provides the user following facilities

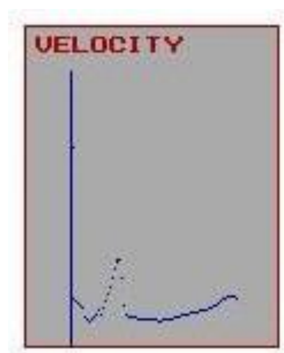
Input : Five bar mechanism with lengths and orientation
Edit : User can modify the parameters
Save : The configuration can be saved
Simulate : The mechanism can rotate and show the coupler curve for points C and D
Database: User can select any configuration from the database
Input : Motion Curve
Matching : Selecting the mechanism to suit the motion curve and edit to get the mechanism to generate the same curve within tolerance limit.



Refer to the general layout of a simple system designed for simulation of five bar mechanism.

The user will be guided to draw the five bar mechanism, starting from the two input links 1-2 and 3-4. Then the user will have to give the point to be traced, point 6. For this discussion, we connect points 2 and 6, and get point 5, which is midpoint of 2-6. Thus we get the auxiliary links 2-5 and 4-5. As the user has already given the orientations of the links 1-2 and 3-4, the simulation tool now can simulate the movement of the mechanism when 1-2 and 3-4 rotate with same angular velocities but in opposite direction. For the user viewing advantage the increment in the angle is 5 degrees so that user can visualize the displacement difference in the successive points on the curve and can get the idea about the velocity as the time interval is constant. More the distance between the successive points, more will be the linear velocity.





The user is provided with the facility to change the position of any point one at a time. This will enable the use to study the effect of each change in the length on the generated curves. The user is also provided with the facility to move point 1 in any direction. This will change the relative orientation of the fixed link 1-3. In this the lengths r1, r2 remain fixed along with point 6. It will automatically adjust the lengths L1 and L2 and user will get a new curve.

IV. RESULTS AND DISCUSSION

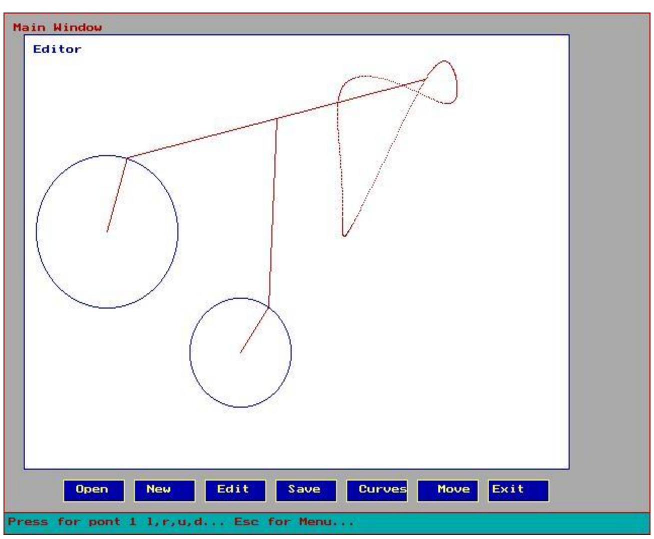
The simulation model is developed for the five bar planar mechanism with constraints. Both the input links are given the same angular velocities. The sense of rotation of input links is opposite to each other. The simulation tool (software) revealed some interesting results in the form of the curves. Effect of the change in the lengths of the links and initial orientation is directly visible on the shape of the curves. The user will have the facility to modify each of the parameter. The change has also affected the velocity at different points on the curve. The motion generation can be studied very effectively using this tool.

The standard four bar mechanisms have a limitation on the generation of the motion curves. All the results which are obtained can be saved for the further use. The user has full freedom to vary any parameter and see the effect. When the entire motion is not possible, the tool generates the error message and the limiting position. The mechanism in such case will keep on oscillating between the limiting positions. The tool has limitations due to the basic constrains which are applied to the rotation of input links. The study will continue further when the input links are provided with different angular velocities. It will also generate more curves of different shapes. The input link velocities can be easily managed by providing the gears with tooth ration 1:1. This will provide same angular velocity and opposite direction.

Five bar planar mechanism with constraints have been explored in recent future but motion generation and coupler curves need to be explored to a large extent. The results shown in this software tool show that the curves can contain straight portions, same path tracing, repeating the same point as well as multiple self intersections.

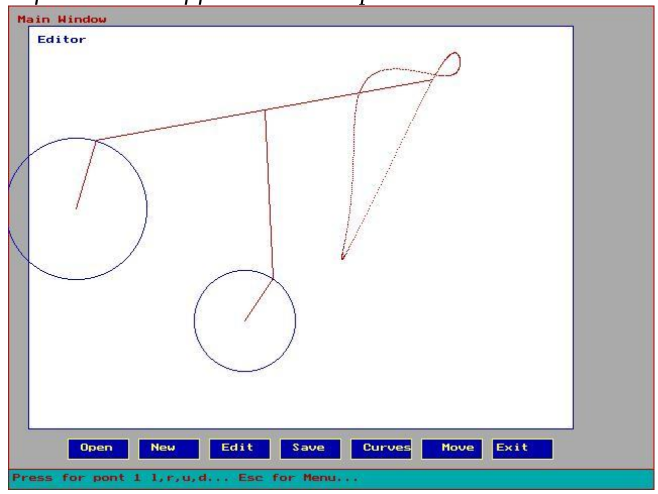
Step by step results

Original Configuration

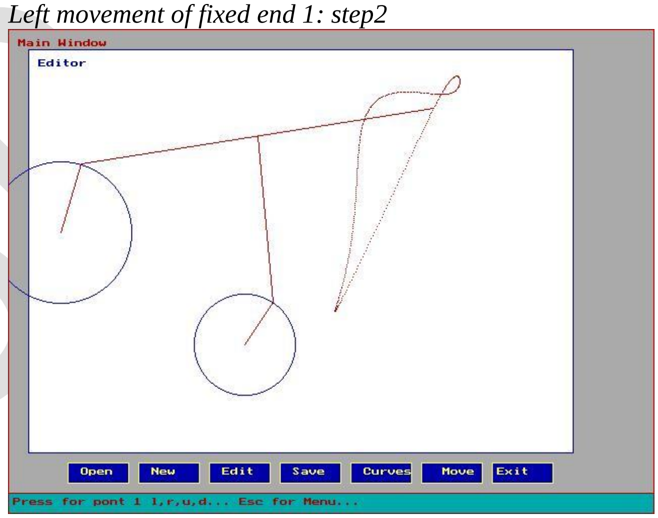


Step by step left movement of fixed end 1is shown next. (For other movements refer to annexure)

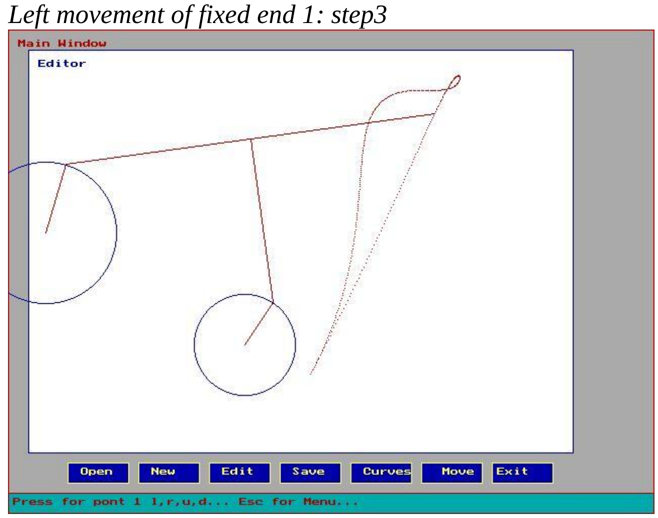
Left movement of fixed end 1: step1



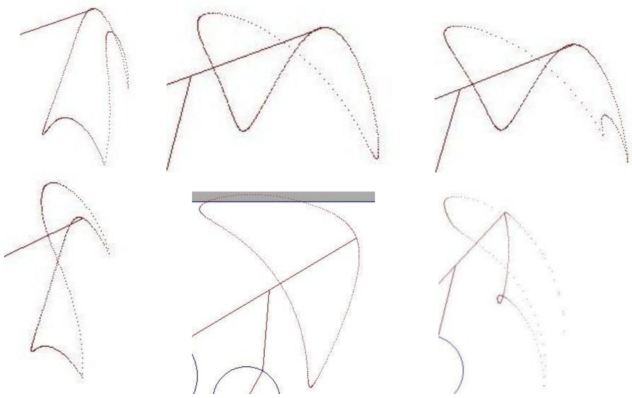
Left movement of fixed end 1: step2



Left movement of fixed end 1: step3

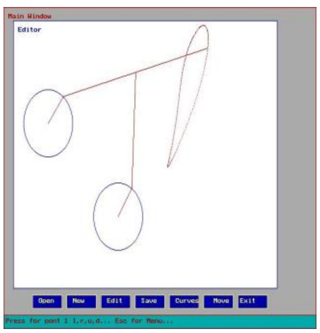


The different curves generated by the simulator are shown below.

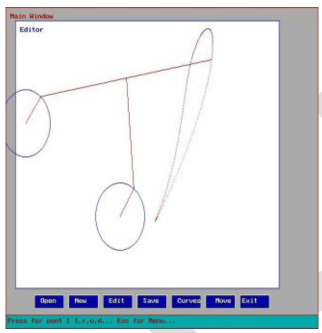


Results of modifications in position of point 1

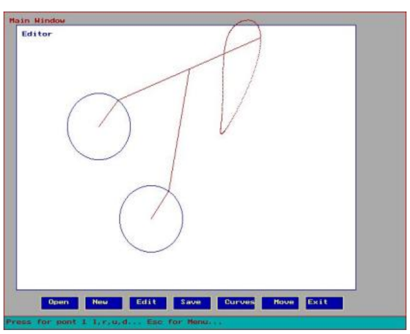
Original Curve



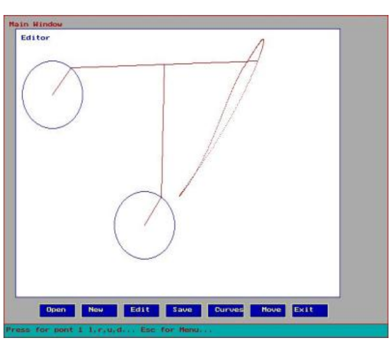
Leftmost position of point 1



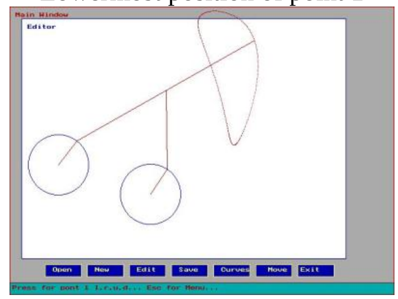
Rightmost position of point 1



Topmost position of point 1



Lowermost position of point 1



V. CONCLUSION

Observing the results obtained from the simulation tool we find that the five bar planar mechanism with rotational constraint is capable of generating a wide variety of curves. The different curves are generated by varying the parameters associated with the mechanism namely, the lengths of the links and initial orientation of the driving links. At the same time we remember that the rotational constraint on the five bar mechanism of same angular velocity and opposite direction can be changed to different ratios of angular velocities and even in same direction. These changes will result in even larger number of curves which can find there applications in the areas like material handling, character animation using motion captured curves. If the concept is used effectively it can be used in industries like embroidery, pattern painting etc.

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