

# Interactive Design System for Creating Mechanical Characters Models

<sup>#1</sup>Abhay K. Abhyankar, <sup>#2</sup>S.Y. Gajjal

<sup>1</sup>abhyankar.abhay@gmail.com

<sup>2</sup>sheshargajjal@gmail.com



<sup>#12</sup>NBN Sinhgad School of Engineering, Ambegaon, Pune

## ABSTRACT

To design an interactive software system that allows users to create animated mechanical characters. The system takes an articulated character as input and also provides the motion curves indicating how different parts of character should move. For each motion curve, the system creates a five bar planar constrained mechanism which reproduces it as closely as possible. The resulting mechanisms are attached to character and then connected to each other using gear trains. The mechanical assemblies generated by the system can be driven by single input driver, hand operated crank or electric motor and can be fabricated using rapid prototyping devices. 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. The scope of the work is limited to characters that perform cyclic motions. System will support wide range of user defined complex motions. For this the system will use a library of parameterized mechanical assembly types.

After the pre-computation step the following steps are used

1. Five bar planar mechanism simulation is designed to view the coupler curves generated. When desired curve is obtained, it can be stored in the library.
2. With articulated character as input, the user selects a set of actuation points on character and sketches the associated motion curves.
3. For each input curve, the assembly that matches motion specified by user is found. The corresponding parameter values will be computed.
4. The driving mechanism is instantiated and connected to character.

**Keywords-** Five Bar Planar mechanism, Coupler curve, Constraints, Motion Curve

## ARTICLE INFO

### Article History

Received : 18<sup>th</sup> November 2015

Received in revised form :

19<sup>th</sup> November 2015

Accepted : 21<sup>st</sup> November , 2015

Published online :

22<sup>nd</sup> November 2015

## I. INTRODUCTION

### 1.1 PROBLEM DEFINITION

To design an interactive software system that allows users to create animated mechanical characters. The system should take an articulated character as input. The articulated character will have the moving parts. The motion curves corresponding to joint of the character will given as the input. The motion curve has to be traced closely by the coupler curve generated by some mechanism. For each motion curve, the system should create a mechanism which

will reproduce it as closely as possible. The resulting mechanisms should be attached to character and then connected to each other using gear trains. The mechanical assemblies generated by the system can be driven by single input driver, hand operated crank or electric motor and can be fabricated using rapid prototyping devices.

### 1.2 OBJECTIVES

The software system which is to be designed has the predefined input and the desired output should match with the expected movement of the character. The input will be

analyzed dimensionally and motion curve is also accepted in the proportionate manner. After the pre-computation step the following steps are used

1. Articulated character will be given as an input. Once the character line diagram is given, the user will select the actuating points. Some points will have dependent motion curve whereas some points will have the independent motion curves. The user will input the independent motion curves. The motion curves will then be associated with the corresponding actuation points.
2. For each input curve, the mechanism which generates the same motion curve will be selected from the existing library of motion curves. Once the mechanism assembly that matches motion specified by user is found. The corresponding parameter values will be computed.
3. The driving mechanism is instantiated and connected to character.
4. Once all the driving mechanisms are set up, the gears that actuate them are connected through a gear train in a semi-automatic fashion.
5. For planar characters, system repositions the components to avoid collisions.
6. Finally the support structures are generated to hold the components of assembly in place.
7. Generate the drawing file with all the components of character, mechanism as well as the support.
8. Using this drawing file it should be possible to get the components cut by laser cutting or VMM.
9. The complete character model and mechanical assembly are then ready for fabrication.

### 1.3 SCOPE & CONSTRAINTS

The system to be designed has several aspects. The system should provide the user with the facility to create a new mechanism in the family and study its motion. The mechanism used is a five bar planar mechanism which is having rotational constraint on the input links. The entire library of the curves can be generated by the user and preserved for the further use. As the input to the five bar mechanism is rotation of one input link and make the interactive software problem tractable, the scope of the work is limited to characters that perform cyclic motions. System should support wide range of user defined complex motions. For this the system should use a library of parameterized mechanical assembly types which will be generated by the same system. As the mechanism to be used is a planar mechanism, the motion of any part of the character should be in a single plane and cyclic. As variety of the curves can be generated, the angular velocity of both the links are considered in opposite sense with same magnitude.

### 1.4 METHODOLOGY

The five-bar mechanism is having degree of freedom 2. By putting the constraint on the two input links, we can reduce the degree of freedom 1. The angular velocities are same but have opposite direction. The initial position of the two links is also a major parameter apart of the lengths of the links. All the variations of the mechanism can only be studied and

simulated using the computer software. The readymade software will not give us the necessary results, instead it is decided that, software should be written for the purpose. The software should be capable of simulating the five-bar mechanism with all the possible orientations and storing the results. This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the conference publications committee as indicated on the conference website. Information about final paper submission is available from the conference website.

## I. LITERATURE REVIEW

In the area of the five-bar mechanism design, *Balli and Chand* (1) introduced a complex number method for the synthesis of a planar five-bar motion generator with prescribed timing. The authors also introduced a method to synthesize a planar five-bar mechanism of variable topology type with transmission angle control. The authors state that it is a unique and non iterative synthesis method that provided a unified approach for motion path and function generations for 2 or more FSP, ISP and MSP synthesis of multilink mechanisms with two or more degrees of freedom acting in more than one phase. The authors have also stated the advantages of the five-bar VTM synthesis method. The first advantage is that the mechanism may be designed for one task in one phase and for a different task in the other phase. Another advantage is the method yields infinite solutions. For obtaining practically useful mechanisms it is necessary to prescribe limits on quantities like transmission angle and max and min link length ratio. They state that condition like equal deviation of transmission angle at two design positions from the ideal  $90^\circ$  may be used as one of the synthesis criteria. The limitations stated by authors are indicating that the mechanism synthesized may suffer from order, branch, Grashof or circuit defects which should be rectified separately. Also for solving the simultaneous equations, it is difficult to find good initial guesses for all possible solutions. *Nokleby and podhorodeski* (2) introduced an optimization method to synthesize Grashof five-bar mechanisms. *Wang and Yen* (3) introduced an approach for synthesizing planar five-bar linkages 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. *Dou and Ting* introduced a method to identify the rotatability and branch condition in linkages containing simple geared five-bar chains. *Lin and Chaing* (5) extended pole method for the use in the synthesis planar, geared five-bar function generators. *Ge and Chen* (6) introduced a software based approach for the atlas method on path synthesis of geared five-bar mechanisms. The two authors also studied the effect of the link length, crank angles and gear tooth ratio on the motion of the geared five-bar linkage. *Li and Dao* (7) introduced a complex number method for the synthesis for geared, five-bar guidance mechanisms. *Cheng and Trang* (8) developed a web based mechanism analysis and animation system. They used Ch, an embedded C/C++ interpreter and Ch mechanism tool kit. *Ceylan, Li, Mitra and others* (9) designed mechanical automata from MOcap sequences. 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. *Zhu, Xu, Snyder and others* (9) developed a new method to synthesize mechanical toys solely from the motion of their features. The entire design is based on cams. *Coros, Thomaszewski, Noris and others* (10) developed an interactive design system for non expert users to create animated mechanical character. Given articulated character as input, the user iteratively creates an animation by sketching the motion curves indicating how different parts of the character should move. They developed a framework which creates an optimized mechanism that reproduces the motion curve as closed as possible to the input motion curve.

## II. DESIGN PROCEDURE

### 3.1 INTRODUCTION

This title “Interactive design system for creating animated mechanical characters” provides us the basic requirements of the entire design. The design system should be capable of accepting the articulated character, mark the actuating points on the character, place the character in the proper orientation, accept the motion curves, attach the motion curves to the respective actuating points, select the mechanism from the library, match the motion curve generated by the mechanism to that given by the user, set the mechanism parameters, show the mechanical character along with the mechanism, animate the individual part movement of the character, generate the motion transfer mechanism like gear train to different mechanisms, animate the entire motion of the character, set the phase difference among different motions and generate the basic dimensional drawing of the different parts. Hence design procedure will be divided into different modules and their integration will give us the necessary output. At the same time, the system should be interactive, which means that the editing and modifying facilities must be provided to the user. When the user will get the drawing for creating the model, even the assembly procedure must be generated for the user. In this chapter, we will discuss the design procedure for each module separately.

### 3.2 MECHANISM & CURVE DATABASE

The system selects the motion curve from the database. There will be no such database readily available. Hence we must provide an editor, which will allow the user to try different parameters for the five bar planar mechanism, simulate it and store it in the database. Hence as the user tries different parameters and configurations, the database built will be strong. The user will have to click the input links along with their orientation. The dimensions are automatically calculated. The user will then generate the coupler arm from first input link. The second input link will be then automatically connected to the midpoint of the coupler link as secondary coupler link. Thus the four links are generated and the fifth link will be fixed link connecting the fixed / non moving ends of the two input links. The angular velocities of the input links are same but the sense is opposite. If the given configuration is valid, then the user will see the entire rotations of the input links and the

generated coupler curve. When the configuration results in locking positions, then the input links will be seen oscillating and the generated curve will not be a closed curve. The user can chose to edit the key points of the mechanism, which will effectively change the length of some link and try for validating the mechanism. On success, user can store the parameters and the curve points in the library, using save option. User is also given the facility to scale the entire mechanism, retaining the shape of the curve. Another facility is to move only input link1, by moving the fixed end, keeping the orientation same. This will gave us the simultaneous change in length of fixed link and rotation of fixed link. The relative orientation of link1 and link 2 also varies. This will give the user some interesting changes in the shape of the coupler curve in steps. Hence user can store the required configuration.

Steps in the design

1. Develop the menu driven editor
2. Accept the 5 bar planar mechanism



Figure 2 : First input link

User will have to enter the first input link.



Figure 3 : Second input link

Then user will give the second input link.

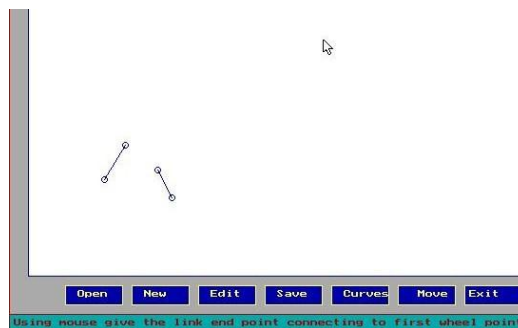


Figure 4 : Coupler link

Now user should give the end point of the coupler link to be connected to the first input link.

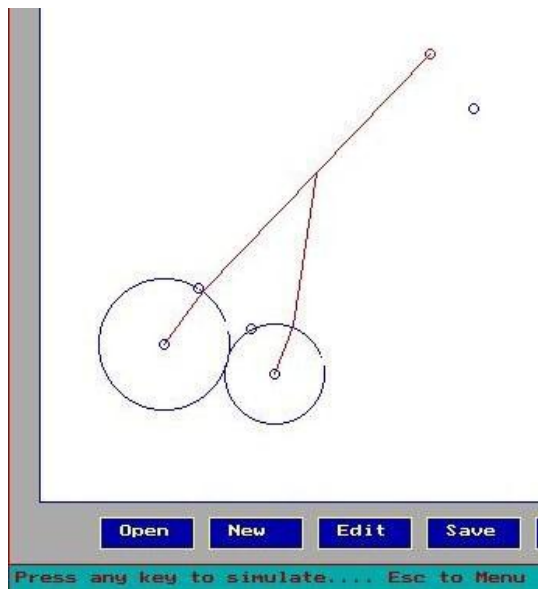


Figure 5 : Five Bar Planar Mechanism

Now the entire five bar mechanism will be shown with the rotations of the input links

3. Apply the mathematical model and represent it graphically
4. Simulate the mechanism to generate coupler curve

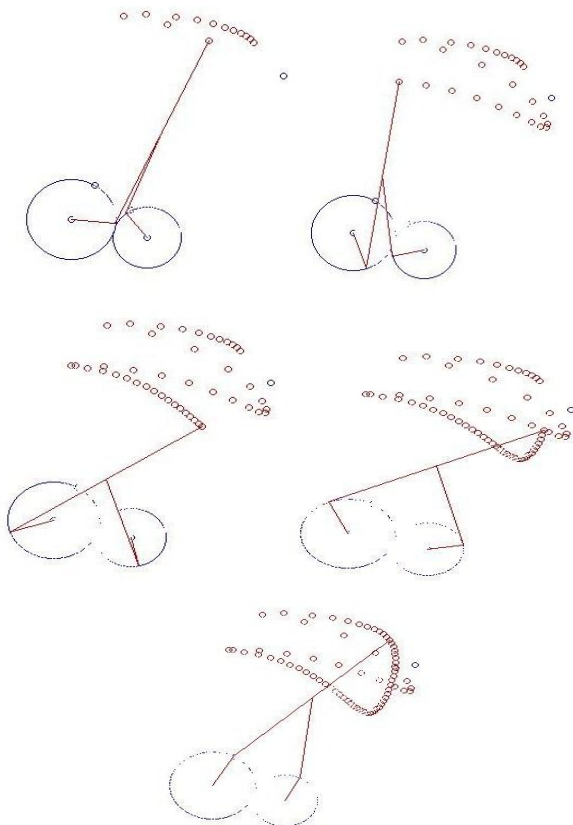


Figure 6 : The Generated coupler curve in steps of the rotation

5. Check for limiting case ( locking positions ) and revert the direction indicating the error.
6. Edit the mechanism for lengths/positions & scale
7. Store the parameters and curve in the file/database

8. Allow the retrieval of the mechanism
9. Allow the selection of mechanism

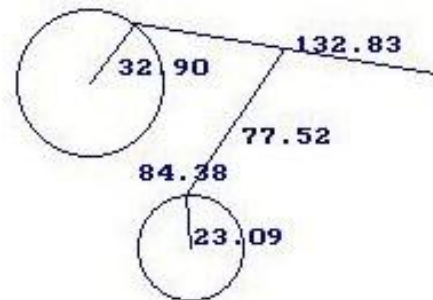


Figure 7 : Mechanism with the dimensions of the links

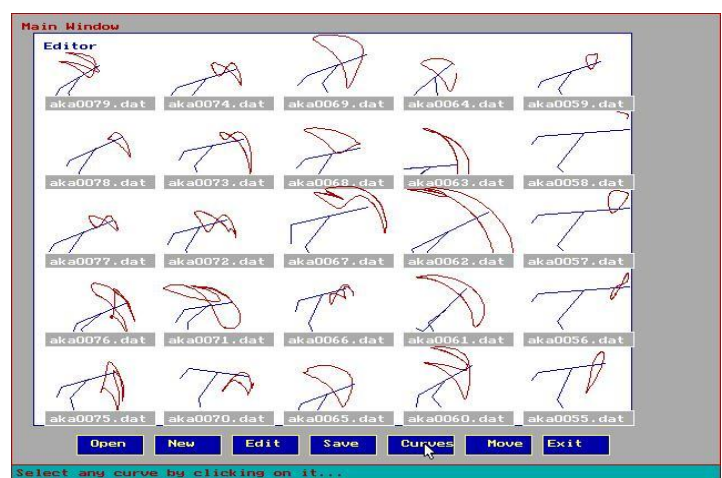


Figure 8 : Library of the curves generated with mechanism orientation

### 3.2 MOTION CURVE

The motion curve will be given by user either as set of points stored in a file or user will actually draw the set of points by mouse click. These points will then be stored in the file for the further use. User can name the file for the motion curve. User can retrieve the motion curve and may scale it or rotate it and again save it. As the number of points given by the user will change, internally the system will interpolate the intermediate points. Once the motion curve is given, user can attach a linkage having 2 bars. This will have three actuating points. The intermediate actuating point will depend on the positions of first and third point as the length of the links will be fixed. Point 1 will always lie on the motion curve, whereas point 2 will be fixed. Now we are required to simulate the motion of the linkage. On acceptance, we can store the motion curve.

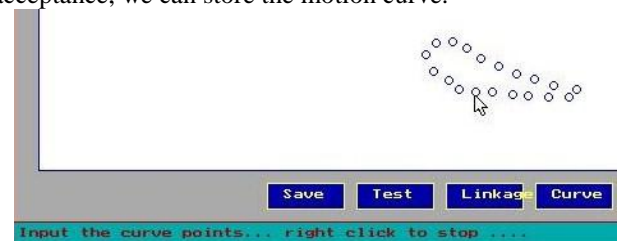


Figure 9 : Motion curve input as set of points



Figure 10 : Motion Curve

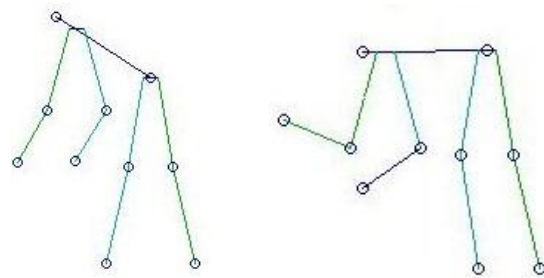


Figure 13 : Different orientations of the human character

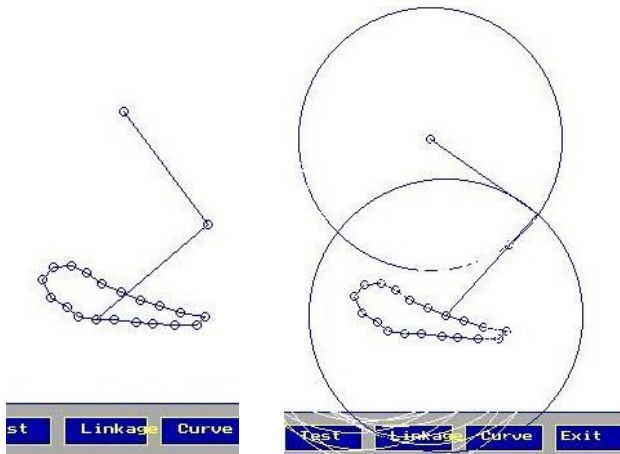


Figure 11 : Motion curve with test link and the simulation

### 3.3 MECHANICAL CHARACTER

For the mechanical character, we are going to consider the human character as the articulated character. It will be shown as a linkage, shown below.

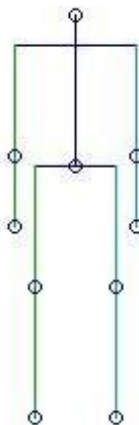


Figure 12: The articulated human character with actuating points

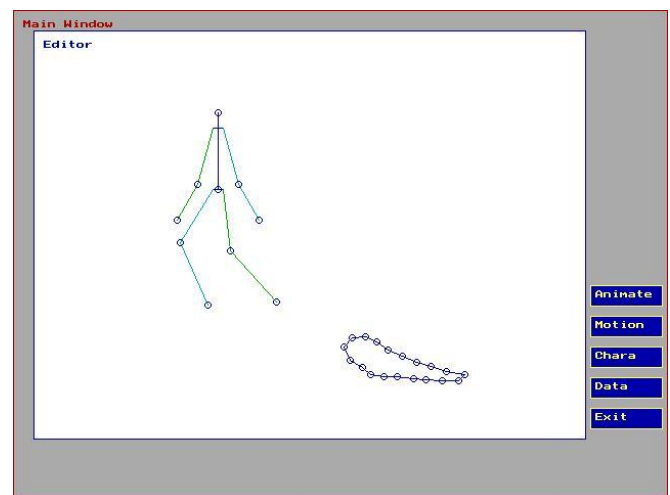


Figure 14 : The character and the motion curve

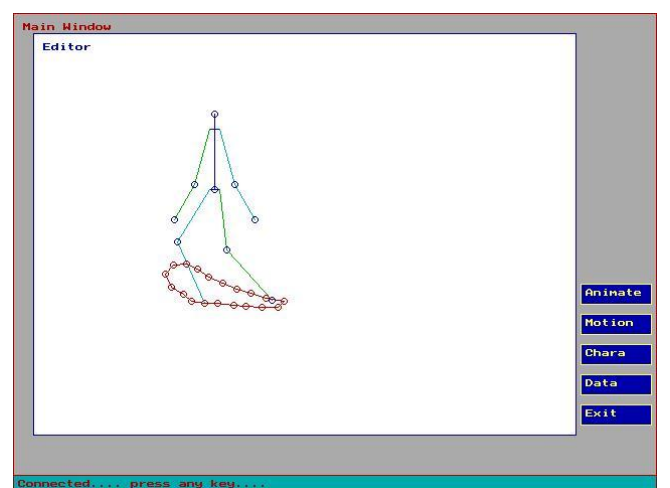


Figure 15 : Motion curve connected to the actuating point

### 3.4 CURVE MATCHING

For finding the mechanism which will generate the same motion curve as the input motion curve, we will have to match the input motion curve and generated motion curve. The curve matching technique is to be invented. To make



curve matching completely automated, it will be a very time consuming job. To simplify the task, we let the user select the mechanism which generates the similar curve in shape. Now the user is given a facility to scale the mechanism, in turn scaling the curve, to move one end of the fixed link to modify the shape within the scope of the family of the curves generated by the same mechanism, to rotate the mechanism to achieve the same orientation as the input curve.

### 3.5 MECHANISM CONNECTIONS

As each point on the articulated character is associated with different motion curve or a phase difference and we need to provide a single input, we must connect these mechanisms or their individual input links by gear trains. Input link of each mechanism will be thus connected to the master input link.

The initial orientation of the input link also must be fixed. If we consider the motion curves for the toe of each leg for human character, we find that the motion curve is same but there is a phase difference, hence we need to set the initial orientation of the input link, which will in turn set the initial orientation of the articulated character.

## III. MATHEMATICAL MODEL OF MECHANISM

### 4.1 FUNDAMENTAL DISCUSSION

The planar five-bar mechanism with revolute joints has degree of freedom 2. By putting the constraint on any link, the degree of freedom can be reduced to 1. In the current discussion we will be considering the planar five-bar mechanism which has two rotating input links connected to fixed link. The two links rotate in opposite direction with same angular velocity. The lengths of these two links need not be same.

Refer to figure 1

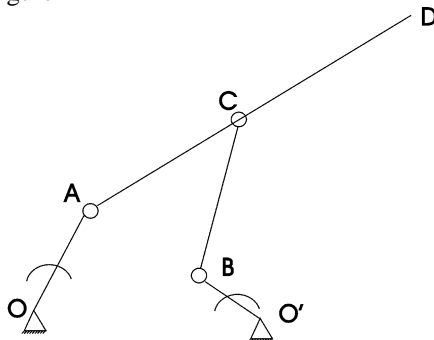


Figure 16 : Five Bar Planar Mechanism Configuration

Link OO' is fixed link. Link OA and O'B are input links, rotating with  $\omega$  and  $-\omega$ .

$$\begin{aligned} l(OA) &= r1 & l(O'B) &= r2 \\ l(AC) &= l1 & l(BC) &= l2 \\ l(AD) &= l = 2 \cdot l1 \text{ as D is midpoint of AC.} \end{aligned}$$

Initial angle made by OA is  $\theta_1$  and O'B is  $\pi - \theta_2$ , with horizontal. All the values except  $\phi_1$  and  $\phi_2$  are known, and we have two equations equating real and imaginary parts. Thus we can determine  $\phi_1$  and  $\phi_2$ . In motion generation, it

is required that point D should approximate to the given curve, as a set of prescribed points. Thus choosing appropriate values of the variables  $r_1, r_2, l_1, l_2, \theta_1, \theta_2$ , we can vary the curve generated by point D. Also the relative positions of OO' and the distance OO' can also be varied. This will generate a family of curves, which can be simulated through the computer software.

### 4.2.2 Constant length geometrical approach

While designing the mathematical model, we use the constant length approach to find the coordinates of the points. It uses the mathematical formulae for the length and circles. The intersection of these circles with each other and the lines will help us to determine the coordinates of the points.

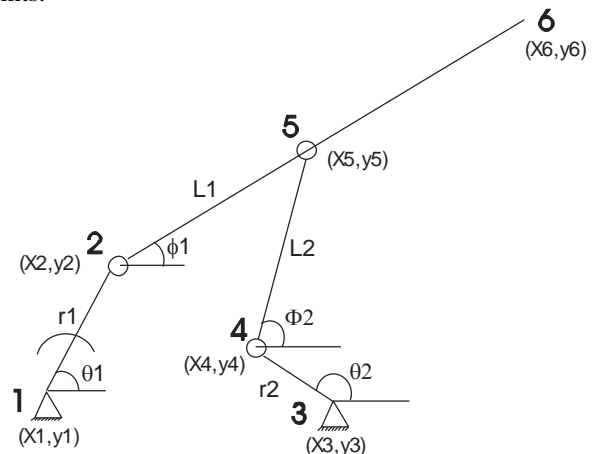


Figure 18: Five bar planar mechanism with dimensions & Coordinates for Constant Length approach

We know  $(x_1, y_1)$  and  $(x_3, y_3)$

Using angles at any moment as  $\theta_1$  and  $\theta_2$

We can find  $(x_2, y_2)$  and  $(x_4, y_4)$  as

$$x_2 - x_1 = r_1 \cos(\theta_1)$$

$$y_2 - y_1 = r_1 \sin(\theta_1)$$

$$x_4 - x_3 = r_2 \cos(\theta_2)$$

$$y_4 - y_3 = r_2 \sin(\theta_2)$$

Circles with centers 2 and 4 having radii  $L_1$  and  $L_2$ , will intersect at point 5.

$$(x - x_2)^2 + (y - y_2)^2 = L_1^2$$

$$(x - x_4)^2 + (y - y_4)^2 = L_2^2$$

Solving these two equations for  $x$  and  $y$

We come across following steps

$$2(x - x_2)k_1 = k_2 + 2y k_3$$

Where

$$k_1 = x_2 - x_4$$

$$k_2 = (L_2 - L_1)^2 - k_1^2 + y_2^2 - y_4^2$$

$$k_3 = y_2 - y_4$$

Finally the quadratic equation

$$a_1 y^2 + b_1 y + c_1 = 0$$

$$\text{where } a_1 = (k_3/k_1)^2 + 1$$

$$b_1 = (k_2/k_1)(k_3/k_1) - y_2$$

$$c_1 = (k_2/2k_1)^2 - L_1^2 + y_2^2$$

The further conditions will be

$$b_1^2 - 4a_1c_1 > 0 \dots \text{necessary to get real value of } y.$$

### 4.2.3.SOFTWARE MODEL

The software model for the planar five bar mechanism is developed using C language with graphic programming. A very simple and user friendly interface is provided. User will work with his/her own idea and can input the mechanism. There will be one line help available for the user. Both keyboard and mouse have their own importance while handling the software model.

It provides the user following facilities

**Input :** Five bar mechanism with lengths and orientation. This will be done only by using the mouse as the points are to be clicked.

**Edit :** User can modify the parameters. Each point of the mechanism can be modified, its position can be changed. Thus only two lengths will be changed at a time.

**Save :** The configuration can be saved. There is an automatic file naming provided.

**Simulate :** The mechanism can be rotated by the use of simple key stroke, one position at a time, leaving the trace of the earlier point. Thus the user can see the coupler curve for points C and D

**Database:** As the mechanism with all the points, lengths will be stored in the file, user can select any configuration from the database

**Input :** Motion Curve can be given as a set of consecutive points.

**Matching :** Selecting the mechanism to suit the motion curve and edit to get the mechanism to generate the same curve within tolerance limit. This will be done by the user in the manual manner.

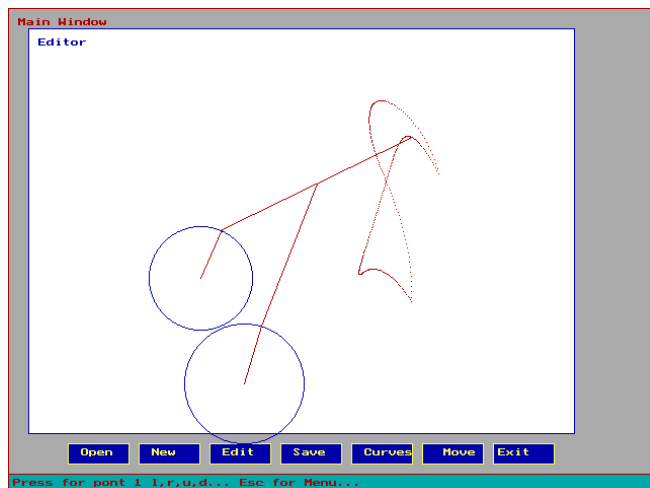


Figure 19 :General user interface for the simulation software

Refer to Figure 19 , which shows 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.

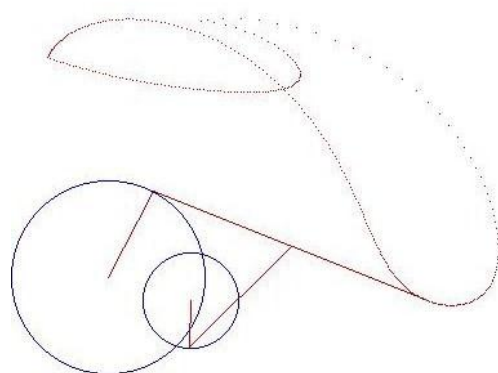


Figure 20 : Five bar planar mechanism with generated curve

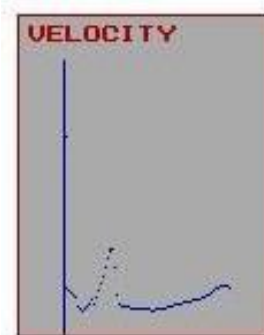


Figure 21 : Velocity diagram for linear velocity of point D or 6

The velocity diagram is based on the time interval for travel between the two successive points.

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  $r_1$ ,  $r_2$  remain fixed along with point 6. It will automatically adjust the lengths  $L_1$  and  $L_2$  and user will get a new curve.

## IV. RESULTS AND DISCUSSION

The software 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 constraints 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 ratio 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. In the next version of the software model, the rotational constraint will be modified to different ratios of angular velocities of input links. In such a case user is free to decide the ratio of the angular velocities and their direction.

### 6.1 Step by step variation of point 1 : Results

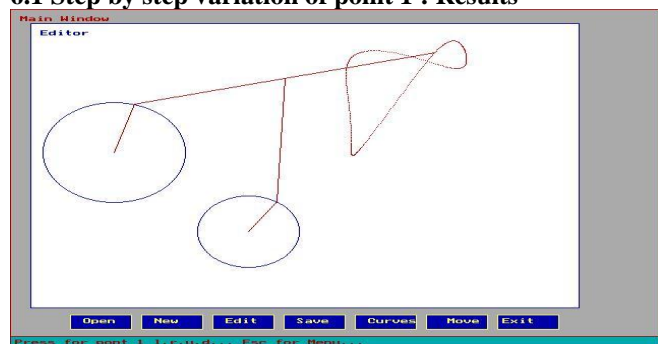


Figure 22 : Original Configuration

Step by step left movement of fixed end 1 is shown next. The original mechanism is retrieved from the database and user is allowed to move only point 1 in any of left, right, up, down direction. This will facilitate the observation related to shape of curve.

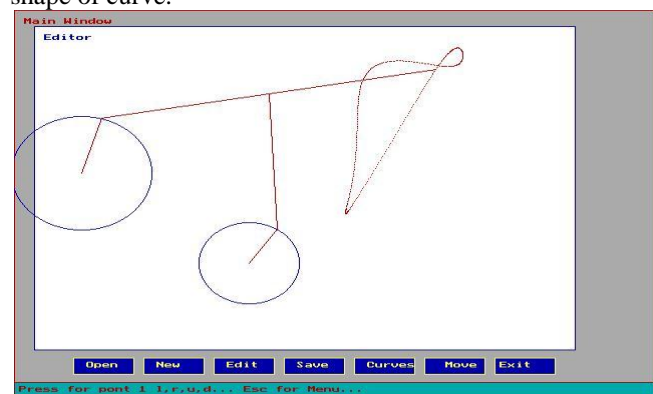


Figure 23 : Left movement of fixed end 1: step1

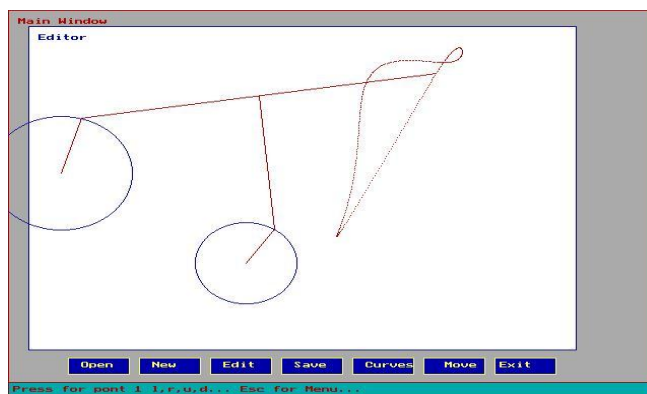


Figure 24 : Left movement of fixed end 1: step2

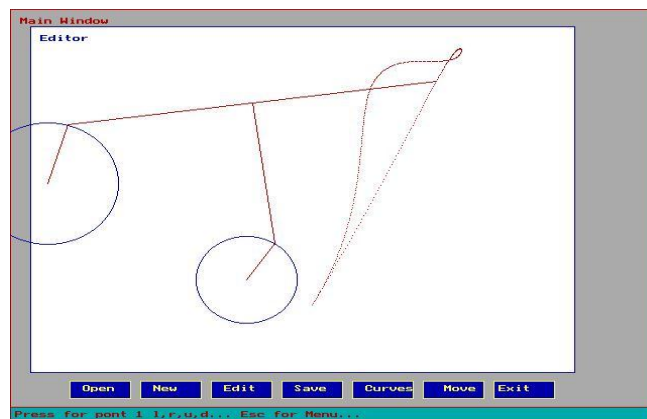


Figure 25 : Left movement of fixed end 1: step3

### 6.2 Curves generated: Results

The different curves generated by the simulator are shown below.

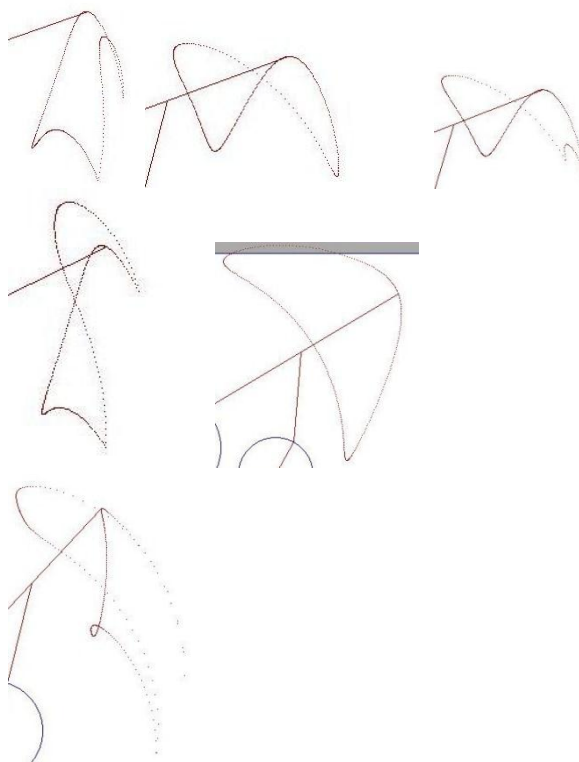


Figure 26 : Some of the curves generated using the simulation software



## V. CONCLUSIONS

Observing the results obtained from the software model 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 be implemented in the next version of this software model. 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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