Effect of change of the orientation of dyad links on kinematics of Stephenson-III six-bar linkage

Tanmay Agrawal, Kushagra Upadhyay, Nitin Sharma and Rakesh Sehgal*
Department of Mechanical Engineering
National Institute of Technology Hamirpur
Hamirpur, Himachal Pradesh, INDIA
rakeshsehgal.nitham@gmail.com

***Abstract*— This paper investigates the kinematic analysis and synthesis of a Stephenson-III six-bar linkage. It is proposed here first as a dwell mechanism (Mechanism A) and later as a double reciprocation mechanism (Mechanism B). Out of the various synthesis techniques, use of coupler curves is adopted for the design of mechanism. Same technique also explains the motion of output link during a complete rotation of input crank. This paper presents the effect of change of dyad links orientation on the kinematic performance of the mechanism. Synthesis has been done assuming the oscillation angle of the crank to be 360°. However the angle, through which the output link oscillates, for each revolution of the input crank can be adjusted. This paper also includes a study of the geometry of the path traced by a coupler point. Use of MATLAB 7.10 and Working Model 2D has been incorporated for the purpose of simulation and analysis of the various orientations. Possible applications of the proposed mechanism are later discussed.**

Keywords*— *Stephenson-III Six bar linkage, Coupler curve, Synthesis of mechanism, Dwell, Double reciprocation.

I. INTRODUCTION

Mechanisms represent the skeleton of machinery. Successful synthesis of mechanisms leads to a successful machine design. Synthesis of mechanism implies design or creation of a mechanism to produce a desired output motion for a given input motion. Mechanism synthesis techniques range from simple graphical techniques going through analytical approach with many assumptions and trials to sophisticated techniques using optimization applications [1]. Synthesis of six bar linkages needs preliminary knowledge of synthesis of four bar linkage as six bar linkage can be thought as a four bar linkage with additional two links called dyad links [2]. The primary mathematical tool for the synthesis of a linkage is known as kinematics equations of the system. Freudenstein introduced a method to use these equations for the design of a planar four bar linkage to achieve a specified relation between the input parameters and the configuration of the linkage [3]. The ability of planar 4-bar mechanism, to generate various kinds of motion, can be greatly enhanced if it is made adjustable. With a simple adjustment of the position of the driven crank fixed pivot(s), a variety of outputs can be obtained with the same set of hardware [4]. A four bar linkage can also be synthesized using the Burmester theory [3], Graphical Synthesis Techniques: 3 positions, Graphical Synthesis Techniques: 2 positions and Coupler curves. Coupler curves from four bar linkages are used in two main ways. The first is to use the motion of the coupler in the area of the curve to perform some function. A common use for such points is in packaging and conveying equipment. A second use for coupler curves is to facilitate the design of six and eight link mechanisms where the output link is to have a prescribed motion relative to the input link [5]. Coupler curves are the best way to trace the entire path in the continuous path generation and for this purpose the traditional tool is the Hrones and Nelson coupler-curve atlas [5, 6]. Appropriate coupler curve for given link lengths is selected for achieving dwelling in a six link mechanism though mechanisms with an exact dwell are not possible in practical engineering due to manufacturing tolerances, vibrations, and backlash [7].

This paper presents the kinematic synthesis of a six-bar linkage proposed here, first as a dwell mechanism and later as a double reciprocation mechanism which on certain change in configuration gives different output. Concept of coupler curve has been utilized here for continuous path generation. The configurations with change of arrangement of dyad links are also presented. Simulation of the mechanism and kinematic analysis of the path traced by a point fixed in the coupler link of the mechanism has also been carried out with focus on dwelling period as well as oscillation and the velocity of output link.

II. KINEMATIC SYNTHESIS

The six-bar linkage presented in this paper and shown in Fig. 1 is a Stephenson III six-bar linkage [8]. The input crank is denoted as link AB, the output link is denoted as link GF, the coupler link is denoted as the ternary link BEC, and the other dyad link as EF. The nomenclature shown in Fig. 1 is used throughout the text of this paper. Use of coupler curve atlas or use of a program that can generate coupler curves is necessary to synthesize such a mechanism. Using Hrones and Nelson [6] coupler-curve atlas or the program hr_crankrocker.m [9], one can obtain various coupler curves that a four bar mechanism can generate for certain given set of link lengths. Preliminary step for the synthesis by the concept of coupler curve includes visualization of shape of the coupler curve that can be used to drive links 5 and 6.Numerous different geometries might be used, but the simplest is a curve of roughly elliptical shape. For an arbitrary four bar linkage,

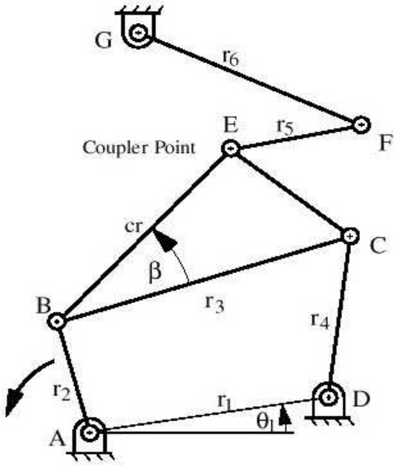


Fig. 1 Stephenson III six-bar linkage [9]

coupler curves are shown in Fig. 2 and hence a suitable curve can be selected as per the requirement with any initial set of dimensions. Out of the coupler curves generated, a curve with nearly circular arcs with adjacent sharp curved sections was selected for mechanism A to dwell the output link during the period when coupler point will trace circular arcs and output link will move while coupler point traces sharp curved sections while for mechanism B a dumble shaped curve was selected in which output link oscillates twice but at different angles.

After selecting a curve, center of the circle that best fits the circular region of the selected coupler curve was found by simulating this four bar linkage in Working Model 2D and by getting the co-ordinates of any three points traced by coupler point to get the equation of circle from it.

For mechanism A: The radius of the circle which can be determined easily from its equation will be length of link EF i.e. r5. Center of this circle will be one extreme position of point F. Point F’ corresponds to the second extreme position of F. To locate F’, any point on the other circular arc is identified. Further, a perpendicular line to coupler curve at this point and with length of link EF as identified earlier is located to locate F’.

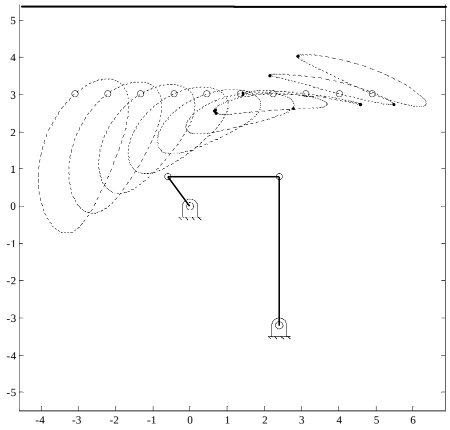


Fig. 2 Coupler curves for a four bar linkage [10]

The pivot G must be located on the perpendicular bisector of the line FF’. With the help of geometry, G is located such that the angle FGF’ is 15o. Initially, the elliptical coupler curve which was selected is shown in Fig. 3 along with the entire mechanism. To get closer to results, flatness of this ellipse was increased further and as a result of which, final mechanism appears as shown in Fig. 4 with a bean shaped coupler curve. The parameters corresponding to the solution given in Table 1.

Variable (Unit)	**Description**	**Variable value**
r_1(cm)	Frame length	1.5
r_2(cm)	Crank length	1
r_3(cm)	Coupler length	2.5
r_4(cm)	Rocker length	2.5
r_5(cm)	Link 5 length	4.75
r_6(cm)	Output link length	2.55
BE (cm)	Coupler radius	4
β (deg)	Coupler angle	35.65^{o}
θ_1 (deg)	Frame angle	0^{o}
G_x (cm)	X coordinate of G wrt A	3.84
G_y(cm)	Y coordinate of G wrt A	1.15

Table 1: Parameters for proposed six link dwell mechanism A

Following the procedure as discussed above, for the given set of link lengths of four bar mechanism, output link length, r6 (in cm) as a function of maximum angle of oscillation, ø (in degree) for a six link dwell mechanism is given by the following equation considering the fact that G will always lie on perpendicular bisector of the line joining the points F and F’:

$$r_6 = 0.33/\sin(f/2)$$

For various values of angle of oscillation, ø for the proposed mechanism, output link lengths are evaluated and presented in Table 2.Using the similar procedure of synthesis, assuming any value of link lengths for the four bar mechanism to generate coupler curve, different solutions can be obtained for a six link dwell mechanism.

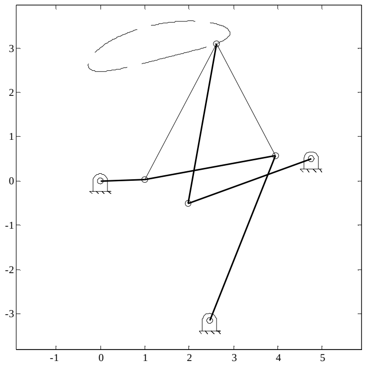


Fig. 3 Elliptical coupler curve [10]

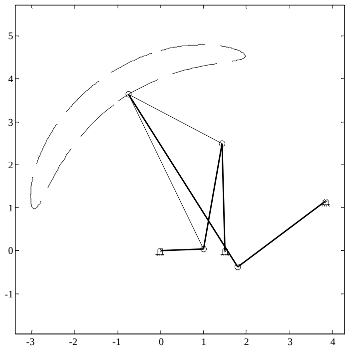


Fig. 4 Bean shaped coupler curve [10]

Angle of oscillation, ø	**Approximate output link length, r_6(cm)**
10°	3.8
20°	1.9
30°	1.275
45°	0.86
60°	0.66
90°	0.47

Table 2: Output link length for various oscillation angles

For mechanism B: Select a coupler curve that is shaped as a dumble. After the coupler curve is identified we select the length of link 5 and tangent to the coupler curve at two points b and d. The centre, F', of this circle is one extreme position of the point F. Draw another circle or circular arc of the same radius tangent to the coupler curve at points a amd c. The centre, F", of this circle is the second extreme position of F. The pivot G must be located on the perpendicular bisector of the line F'F". Locate G such that the angle F'GF" is 30^o. Link 6 is the link from F' to G (or from F" to G). Note there are two possible locations for the point G.

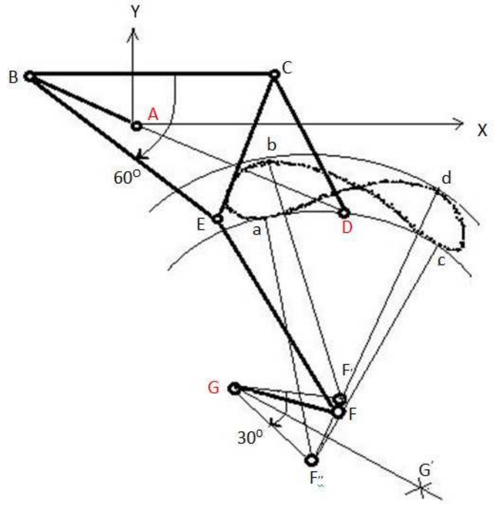


Fig. 5 Mechanism for finding F and G points.

The location G' is chosen, the linkage will lock up before it transverses its entire range of motion. The parameters corresponding to the solution are as follows, refer to Table 3. For various values of angle of oscillation, ø for the proposed mechanism, output link lengths are evaluated and presented in Table 4.Using the similar procedure of synthesis, assuming any value of link lengths for the four bar mechanism to generate coupler curve, different solutions can be obtained for a six link dwell mechanism.

Variable (Unit)	**Description**	**Variable value**
r_1(cm)	Frame length	2
r_2(cm)	Crank length	1
r_3(cm)	Coupler length	1.75
r_4(cm)	Rocker length	1.5
r_5(cm)	Link 5 length	3.63
r_6(cm)	Output link length	1.329
BE (cm)	Coupler radius	1.97
β (deg)	Coupler angle	-36.44^o
θ_1 (deg)	Frame angle	-28.39^o
G_x (cm)	X coordinate of G wrt A	3.2
G_y(cm)	Y coordinate of G wrt A	-3.25

Table 3: Parameters for proposed six link oscillation mechanism B

S.No.	**Angle of oscillation, ø**		**Approximate output link length, r_6(cm)**		**r_6 (cm)**
	P	**Q**	**P r_6**	**Q r_6**	**$r_{6\ Final}$**
1	5°	10°	7.895	7.62	7.7575
2	10°	20°	3.947	3.83	2.885
3	15°	30°	2.63	2.56	2.595
4	20°	40°	1.98	1.94	1.96
5	22.5°	45°	1.76	1.73	1.745
6	25°	50°	1.58	1.57	1.575
7	30°	60°	1.329	1.329	1.329
8	45°	90°	0.899	0.9	0.8995

Table 4: Output link length for various oscillation angles

$$P = r_6 = 0.34405/\sin(f/2)$$

$$Q = r_6 = 0.6645/\sin(f/2)$$

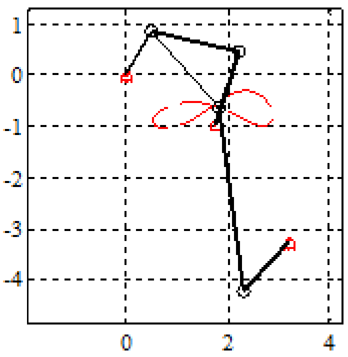


Fig. 6 Dumble shaped coupler curve [10]

Same procedure can be applied for the synthesis of any kind of six link mechanism by appropriate choice of coupler curve assuming any arbitary four bar linkage.

III. SIMULATION AND ANALYSIS

For each synthesis, a simulation has been carried out to check the dwell period, oscillation and variation of velocity of output link with input link. Simulation has been done on Working Model2D. Working Model 2D has the features of easily tracing any point fixed on any link of the mechanism [11]. Analysis of dwelling and velocity has been done using the MATLAB 7.10 routine sixbar.m [9]. It is observed that in the results, the angular velocity of link 6 is approximately zero during the dwell. Input crank velocity has been assumed as 1 rad/s throughout the analysis of mechanism. The results of simulation are discussed and graphically represented in the following paragraphs.

For the mechanism A with elliptical coupler curve, variation of output link velocity with input rotation is shown in Fig. 7 which helps to note the dwelling period of output link while the variation of output angular displacement with input rotation is shown in Fig. 8 which helps to find the maximum angle through which output link oscillates. As can be seen from Fig. 7 and Fig. 8, output link is dwelling for input crank rotation from approximately 90° to 160°.

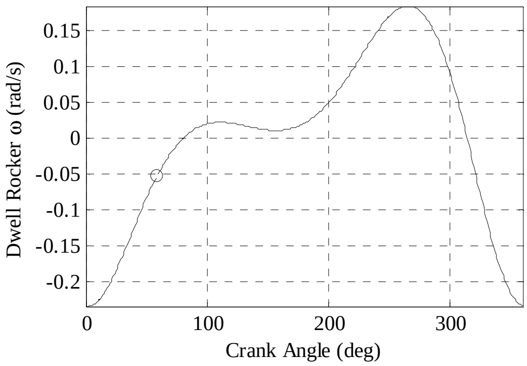


Fig. 7 Dwelling of mechanism with ellptical coupler curve [10]

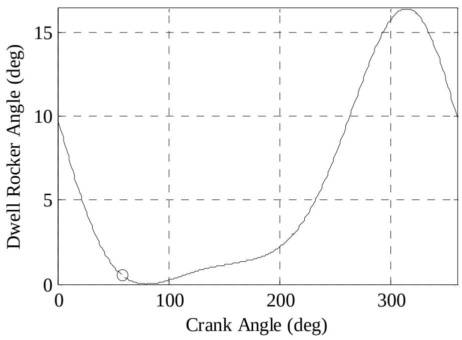


Fig. 8 Oscillation of mechanism with ellptical coupler curve [10]

It can also be seen that the maximum angle through which the output link oscillates is more than 15°.That is why the flatness of the ellipse had to be increased. For the mechanism with bean shaped coupler curve, variation of output link velocity with input rotation is shown in Fig. 7 which helps to determine the dwelling period of output link while the variation of output angular displacement with input rotation is shown in Fig. 8 which helps to note the maximum angle through which output link oscillates. As can be seen from Fig. 9 and Fig. 10, output link is dwelling for input crank rotation from approximately 140° to 210°. It can also be seen that the maximum angle through which the output link oscillates is almost 15°. Variation of velocity of rocker arm i.e. link CD for bean shaped coupler curve is shown in Fig. 11 while the variation of rocker angle for the same is shown in Fig. 12.

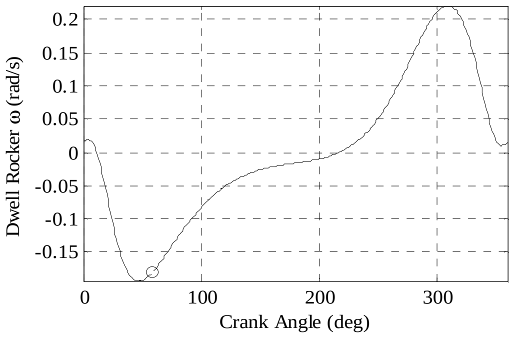


Fig. 9 Dwelling of mechanism with bean shaped coupler curve [10]

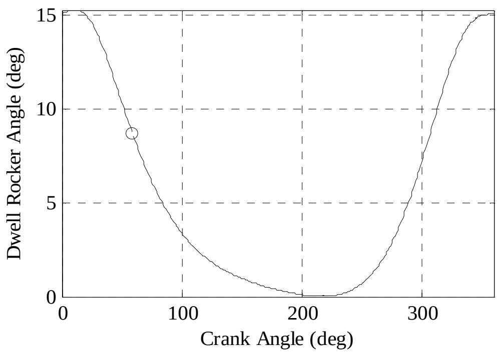


Fig. 10 Oscillation of mechanism with bean shaped coupler curve [10]

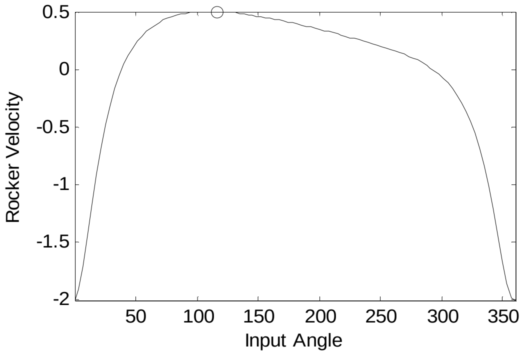


Fig. 11 Variation of rocker velocity for mechanism with bean shaped coupler curve [10]

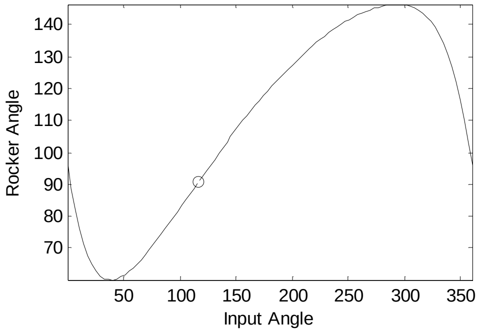


Fig. 12 Variation of rocker angle for dwell mechanism [10]

For the mechanism B with dumble shaped coupler curve, variation of output link velocity with input rotation is shown in Fig.13 which helps to note the oscillation of output link with input rotation. Variation of output link angle with input rotation is shown in Fig.14 which helps to find the maximum angle through which output link oscillates. As can be seen from Fig.13 and Fig. 14, output link is oscillates to 30^o and 60^o in the intervals. 100^o-300^o and 0^o-100^o , 300^o-360^o respectively for input crank. It can also be seen that the maximum angle through which the output link oscillates is 60^0. For the mechanism with dumble shaped coupler curve, variation of output link velocity with input rotation is shown in Fig. 13 which helps to determine the oscillation of output link while the variation of output angular displacement with input rotation is shown in Fig. 14 which helps to note the maximum angle through which output link oscillates.

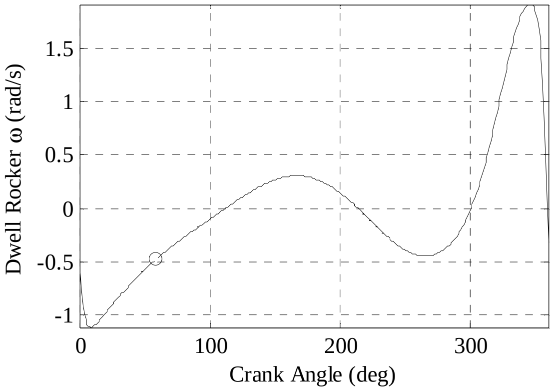


Fig. 13 Variation of output link velocity with input Crank angle

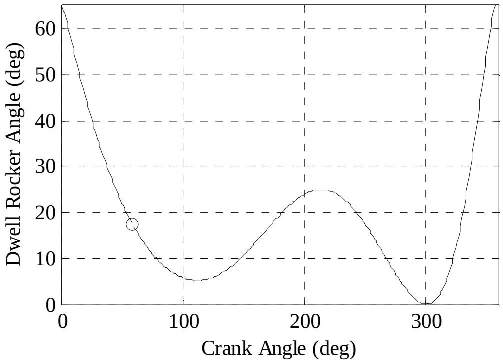


Fig. 14 Variation of output link oscillation angle with input

Another orientation for Mechanism A that has been mentioned in this study is obtained by changing the arrangement of dyad links. If the joint between dyad links is made above C instead of making it below C, mechanism is said to exist in another configuration. By changing the location of joint, this dwell mechanism changes into a mechanism with no dwelling period. However, coupler point in both the cases traces the same path. For second orientation, output link moves continuously with input link rotation. Configuration for this orientation is shown in Fig. 15. Difference can be noted as the joint between dyad links as shown in Fig. 4 occupies a different position in Fig. 15. This configuration when simulated and analysed, showed completely different characterstics from the dwell mechanism.Variation of velocity of outputlink with input link rotation is shown in Fig. 16. The common point between dyad links i.e. the joint between the two links, is shown in Fig. 17 along with the bean shaped coupler curve. Path tracing is the result of simulation done in Working Model 2D. It can be seen from Fig. 17 that the path traced by dyad joint is an arc.

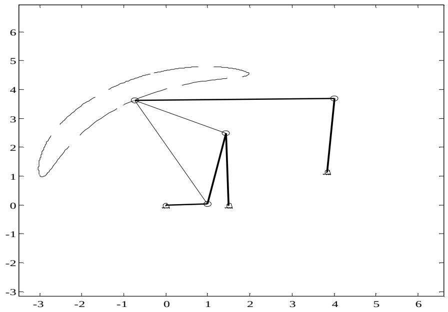


Fig. 15 Alternative orientation for Mechanism A proposed in this study [10]

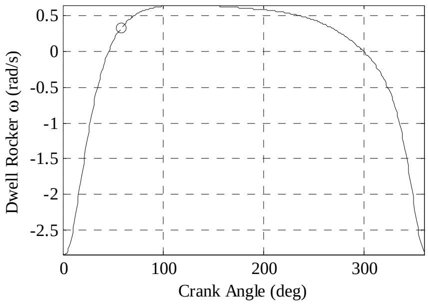


Fig.16 Variation of output link's velocity in alternate orientation for mechanism A [10]

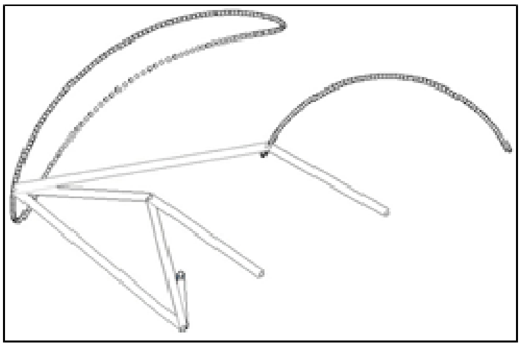


Fig. 17 Path traced by dyad links' joint in alternate orientation for mechanism A[11]

Another result obtained from simulation that gives the variation of angle through which output link rotates with input rotation is shown in Fig. 18. As can be seen from Fig. 18, there is no period of input link rotation for which dwell rocker angle or the angle through which output link rotates remains constant. Thus there is no dwell occuring in this configuration. From Fig. 16, it is easy to interpret that output link reciprocates in an arc between two defined points separated though an angle of approximately 120°.

For Mechanism B, alternate orientation that has been mentioned in this study is obtained by changing the arrangement of dyad links. If the joint between dyad links is made above C instead of making it below C, mechanism is said to exist in another configuration. By changing the location of joint, this no dwelling mechanism changes into a mechanism with dwell period. However, coupler point in both the cases traces the same path. For second orientation, output link dwells for certain time with input link rotation.

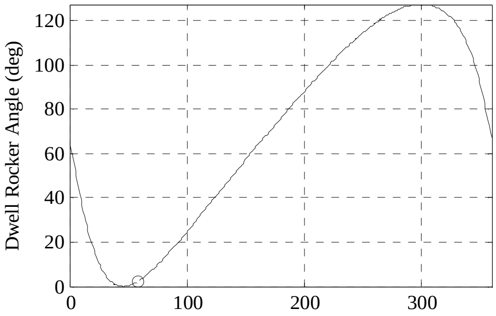


Fig.18 Variation of angular displacement of output link in alternate orientation for mechanism A [10]

Configuration for this orientation is shown in Fig. 19(A). Difference can be noted as the joint between dyad links as shown in Fig. 19(A) occupies a different position in Fig. 6 This configuration when simulated and analysed, showed completely different characterstics from the oscillatory mechanism.Variation of velocity of outputlink with input link rotation is shown in Fig. 19(C). The common point between dyad links i.e. the joint between the two links, is shown in Fig. 19(A) along with the dumble shaped coupler curve.

Practical design of the Mechanism A proposed along with the alternate configuration is shown in Fig. 20.Acrylic has been used for the purpose of fabrication of mechanism.Other materials can also be used for this purpose depending upon the nature of situation.

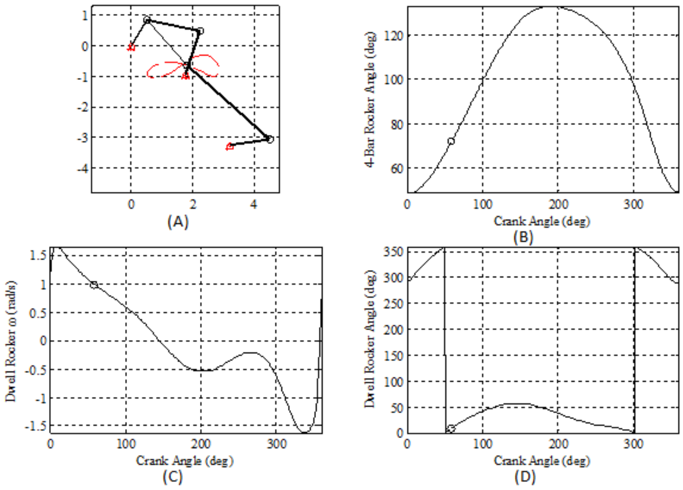
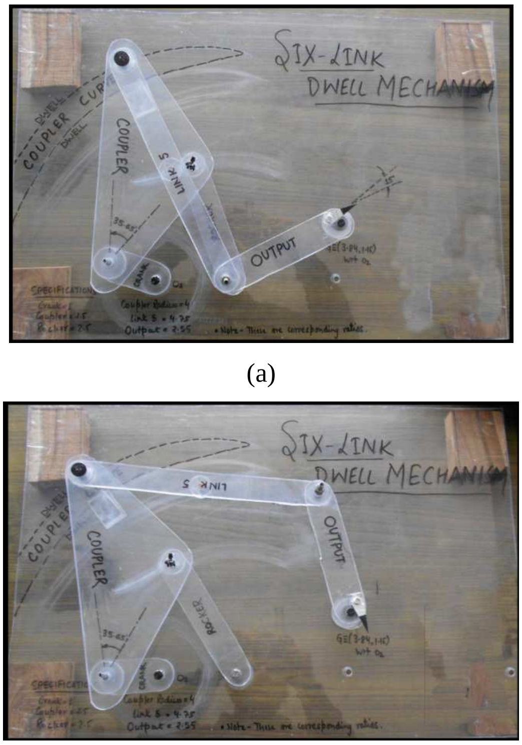


Fig. 19 Alterantive orientation of Mechanism B along with its characterisic input output plots [10]



(a)

(b)

Fig. 20 Practical design of (a) Dwell mechanism and (b) Alternate configuration for Mechanism A

IV. APPLICATIONS

The two configurations discussed in this paper can be used as per the requirement. Six link mechanisms are used where dwelling, reciprocation, double oscillation etc. is required [5]. Dwell mechanisms have numerous applications in many industries, especially for automation [2]. In this paper, the proposed six link mechanism is used as a dwelling and a reciprocating mechanism. When dyad links' joint of this six bar mechanism lies below the point C, as shown in Fig. 4,the mechanism dwells and its motion can be utilized at places where dwelling is required between motion. For example, an assembly line, where dwelling is required between continuous motion for performing operations on the component. From Fig. 7, it can be observed that output link reciprocates and dwells for complete rotation of input link. In assembly line, in first half of crank rotation, output link will move the component, and for certain period afterwards, because of the dwell of output link, operations will be performed on the component. Finally, in the second half, since the output link will go back to its initial position, there is a need for an auxiliary component like a gear to move the component still forward. Hence this dwell mechanism can be used to move and operate a component on an assembly line. This mechanism can also find application in numerous operations such as stamping, punching etc. in which energy has to be supplied intermittently as it can be seen that rocker arm acquires as well as release its kinetic energy very quickly. It can impart this energy to any component if it comes in appropriate contact. When simulation made on Working Model 2D was observed, it can be noticed that output link can be treated as the handle of hand pump. In other words, it can also be used at places, where hand pump mechanism is required. It can be done by adjusting the maximum angle through which output link oscillates for complete crank rotation. Now on the other hand, if the dyad links' joint is above point C, as shown in Fig. 11 output link reciprocates thus resulting in its application as a car wiper mechanism. It can be used at those places where continuous angular reciprocating motion is required for complete rotation of input crank. For both of the configurations, coupler point traces same and a very interesting path. Motion of coupler point with integration of robotics can also be utilized in making a pick and place mechanism.

V. CONCLUSIONS

This paper presented a brief on synthesis of a six link mechanism using coupler curves for a four bar linkage, which is proposed here as a dwelling mechanism, which on changing its orientation changed its behavior, input-output relationships. In one orientation, for complete rotation of input link, output link dwelled for some period of input rotation. While in other orientation, output link reciprocated for complete rotation of input link. The paper also investigated various coupler curves that might be possible for any given four bar configuration. The work presented in this paper provides geometrical insight into the kinematic analysis and synthesis of an orientation dependent six-bar linkage, in particular, and planar single-degree-of freedom mechanisms, in general. Linkage-type dwell mechanisms are less expensive to manufacture and maintain. They are also easily adjustable for satisfying variable output motion requirements. In spite of these advantages they have not found wide application. Part of the reason for this lack of popularity is the absence of proper design tools. Hence further work is required in order to develop efficient design tools for best utilization of their applications.

ACKNOWLEDGMENT

The authors greatly acknowledge the support extended by Department of Mechanical Engineering, NIT Hamirpur in terms of lab facilities during the course of this work.

REFERENCES

[1] Galal A. Hassaan, Mohammed A. Al-Gamil and Maha M. Lashin, New Approach for the Synthesis of Planar 4-Bar Mechanisms for 2 Coupler-Positions Generation, New York Science Journal 2012; 5(10): 86-90.

[2] Huimin Dong and Delun Wang, New approach for optimum synthesis of six-bar dwell mechanisms by adaptive curve fitting, Proceedings of 12th World Congress in Mechanism and Machine Science ; IFToMM 2007 – June 17 – 21, 2007 , Besancon, France.

[3] Ajay A. Dhore, Dr. R.D.Askhedkar,Synthesis of Four bar mechanism by Freudenstein Equation, International Journal of Engineering Research and Applications, Vol. 2, Issue 5, September- October 2012, pp.999-1002

[4] A. Ahmad, K.J. Waldron, Synthesis of adjustable planar 4-bar mechanisms, Mechanism and Machine Theory 14 (6) (1976), 405–411

[5] Kenneth J. Waldron, Gary L. Kinzel, Kinematics, Dynamics and Design of Machinery, 2nd edition, John Wiley & Sons, 2004.

[6] Hrones, J. A., and G. L. Nelson, Analysis of the four bar linkage, The Technology press of M.I.T., Cambridge, MA, and John Wiley & Sons, New York(1951).

[7] Gordon R. Pennock, Ali Israr, Kinematic analysis and synthesis of an adjustable six-bar linkage, Mechanism and Machine Theory 44 (2009) 306–323.

[8] Chunhui Chung and Chintien Huang, On the Rotation Curves of Stephenson III Six-Bar Linkage, 13th World Congress in Mechanism and Machine Science, Guanajuato, M´exico, 19-25 June, 2011, paper no. A7-449

[9] Compact Disk(CD) provided with the book Kinematics, Dynamics and Design of Machinery by Kenneth J. Waldron et. al.(2004).

[10] Amos Gilat, MATLAB: An Introduction with Applications, 2nd edition, John Wiley & Sons, 2004.

[11] Knowledge Revolution, Working Model 2D: Version 4.0, 1996.