The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 12 || Series II || Pages || PP 61-65 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Analysis of the position and velocity of a slider-crank mechanism

[1]Yael Valdemar Torres Torres, [2]Brenda Carolina Pérez Millán, [1]Erasto Vergara Hernández, [1]César Eduardo Cea Montufar

[1] *UPIIH, Instituto Politécnico Nacional, Unidad Profesional Interdisciplinaria de Ingeniería Campus Hidalgo, México*

[2] *CECyT 19, Instituto Politécnico Nacional, Tecámac, Estado de México, México*

Corresponding Author: breca_mec83@hotmail.com

ABSTRACT

In the present work, a didactic application is required and implemented to approach the study of the analysis of a crank-slider mechanism's position and velocity. It is based on the mathematical analysis of the closed-loop equation and the vector analysis of the mechanism's velocities. A graphical interface is implemented in the MATLAB GUIDE visual platform. The results are displayed numerically and graphically of the positions' values and angular velocities of the crank-slider mechanism. The program can be a powerful tool in learning mechanism analysis for mechanical engineering students.

KEYWORDS: *slider-crank mechanism, analysis velocity and position, closed-loop*

Date of Submission: 16-12-2020 | Date of Acceptance: 02-01-2021

I. INTRODUCTION

The four-bar mechanism study has been studied extensively during the last years and implemented in the machine systems within the different manufacturing processes of today; the number of applications of the four-bar mechanism is estimated to be more than 1,000. These include oil wells, car windshield wipers, internal combustion engines, front-wheel suspensions [1-4]. An example of a four-bar mechanism widely used in the engineering area is the slider-crank mechanism. The crank is the rotating element connected to a rigid rod called the connecting rod, which performs a forward and backward movement.

On the other hand, the use of information technology in education has been driven by computers rapid development, transforming how students acquire knowledge in a significant way. This topic has presented the need to develop programs and applications for use in classrooms at different educational levels. In mechanical engineering, information technology is a powerful tool for use in the teaching-learning process, and the developed program contributes to the analysis of the study of mechanisms by linking technological tools to streamline the mechanical review and create added value.

In this work, a didactic application was created with the purpose of supporting students who take a course on mechanism analysis so that they can obtain and strengthen knowledge on the subject of analysis of the position and speed of a crank-connecting rod-sliding mechanism.

II. METHODS

The program was implemented in the GUIDE graphic environment of Matlab, which allows the student to know the linear speed of the slider-crank mechanism and the angular velocity of the links of the crank and slider. The analysis starts with the settings shown in Figure 1.

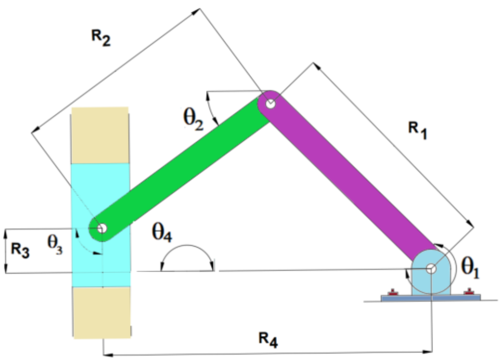

Figure 1- Configuration of the four-bar mechanism to be studied.

The analysis is carried out from the closed loop equation (equation 1) through the complex variable diagram shown in Figure 2. [5].

$$\vec{z_1} + \vec{z_2} + \vec{z_3} + \vec{z_4} = 0 \quad (1)$$

where the representation in exponential form for the complex numbers of each link is:

$z_n = R_n e^{i\theta_n}$

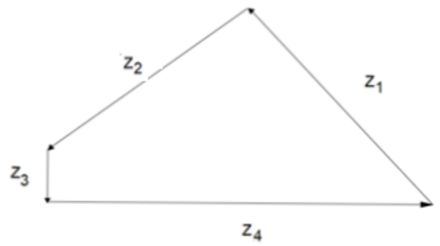

Figure 2- Vector diagram of the crank-slider mechanism.

For the analysis, the length of link 3 (R_3) and the length of link 4 (R_4) will be taken as unknown variables, it is worth mentioning that due to the configuration of the mechanism, the value of the angle taken by both $\boldsymbol{\theta_3}$ and $\boldsymbol{\theta_4}$ will be: 0° , 90°, 180°, 270° or 360° in most cases, however it can be specified by the user.

Developing equation 1:

$$\boldsymbol{R_1 e^{i\theta_1} + \mathrm{R_2 e^{i\theta_2}} + \mathrm{R_3} e^{i\theta_3} + R_4 e^{i\theta_4} = 0} \quad (2)$$

Decomposing equation (2) into its real part:

$$\boldsymbol{R_1 cos\, \theta_1 + R_2 cos\, \theta_2 + R_3 cos\, \theta_3 + R_4 cos\, \theta_4 = 0} \quad (3)$$

and in its imaginary part:

$$\boldsymbol{R_1 sen\, \theta_1 + R_2 sen\, \theta_2 + R_3 sen\theta_3 + R_4 sen\, \theta_4 = 0} \quad (4)$$

Solving for the variables R_3 and R_4 from equations (3) and (4), and expressing the result in a matrix, we obtain:

$$\begin{bmatrix} \mathbf{cos}\, \boldsymbol{\theta_3} & \mathbf{cos}\, \boldsymbol{\theta_4} \\ \mathbf{sen}\, \boldsymbol{\theta_3} & \mathbf{sen}\, \boldsymbol{\theta_4} \end{bmatrix} \begin{bmatrix} \boldsymbol{R_3} \\ \boldsymbol{R_4} \end{bmatrix} = \begin{bmatrix} \boldsymbol{-R_1 cos\theta_1 - R_2 cos\theta_2} \\ \boldsymbol{-R_1 sen\theta_1 - R_2 sen\theta_2} \end{bmatrix} \quad (5)$$

Equation (5) is of the form $\boldsymbol{Ax = b}$, so it can be solved by the expression: $\boldsymbol{x = A^{-1}b}$, obtaining the formula of the equation (2):

$$\begin{bmatrix} R_3 \\ R_4 \end{bmatrix} = -\frac{1}{sen(\theta_4 - \theta_3)} \begin{bmatrix} sen\theta_4 & -cos\theta_4 \\ -sen\theta_3 & cos\theta_3 \end{bmatrix} \begin{bmatrix} R_1 cos\theta_1 + R_2 cos\theta_2 \\ R_1 sen\theta_1 + R_2 sen\theta_2 \end{bmatrix} \quad (6)$$

The kinematic analysis to find the angular velocity of the crank and connecting rod, will have as delivery variables the angular positions ($\boldsymbol{\theta_N}$)) of each link and the linear velocity of the sliding mechanism (V_c).

The velocity of point B, $\overrightarrow{\boldsymbol{V_B}}$ is:

$$\overrightarrow{\boldsymbol{V_B}} = \overrightarrow{\boldsymbol{V_A}} + \overrightarrow{\boldsymbol{\omega_{AB}}}\, \boldsymbol{x}\, \overrightarrow{\boldsymbol{r_{AB}}} \quad (7)$$

Substituting the vectors in Eq. (7) and considering $\overrightarrow{\boldsymbol{V_B}}$ =0

$$\overrightarrow{\boldsymbol{V_B}} = \boldsymbol{\omega_{AB} R_1\, cos\, \theta_1\, \hat{j} - \omega_{AB} R_1\, sen\, \theta_1\, \hat{\imath}} \quad (8)$$

Velocity of point B, $\overrightarrow{\boldsymbol{V_B}}$ is:

$$\overrightarrow{\boldsymbol{V_B}} = \overrightarrow{\boldsymbol{V_C}} + \overrightarrow{\boldsymbol{\omega_{BC}}}\, \boldsymbol{x}\, \overrightarrow{\boldsymbol{r_{BC}}} \quad (9)$$

Substituting the vectors in Eq. (9) we have:

$$\overrightarrow{V_B} = V_c\,\hat{j} + [\omega_{BC} R_2 \cos\theta_2\,\hat{j} - \omega_{BC} R_2 \operatorname{sen}\theta_2\,\hat{\imath}] \qquad (10)$$

Equating Eq. (8) and Eq. (10) we find the following system of equations:

$$\begin{bmatrix} R_1 \operatorname{sen}\theta_1 & R_2 \operatorname{sen}\theta_2 \\ -R_1 \cos\theta_1 & -R_2 \cos\theta_2 \end{bmatrix} \begin{bmatrix} \omega_{AB} \\ \omega_{BC} \end{bmatrix} = \begin{bmatrix} 0 \\ V_c \end{bmatrix} \qquad (11)$$

In the programming stage, the flow diagram was carried out and implemented with the operations shown in Figure 3. The start of the program occurs with the acquisition of the data of the length and angular position of the crank and the connecting rod, as well as the linear speed and angular position of the sliding mechanism, finally, the angular position of link four. The angular measurements must be in the sexagesimal system.

The next step in the program structure is to program the solutions of the lengths R_3 and R_4 as well as to find the angular velocities of the crank (ω_{AB}) and the connecting rod (ω_{BC}), the solutions are found with Eq. (6) and Eq. (11) respectively, then the results are displayed in the interface and in parallel the final configuration of the mechanism under study is plotted for compression by the student.

To show the final graph of the crank-slider under study, functions were used to draw lines through two points, which represent the Cartesian coordinates of the joints of each link and use an origin reference frame (0,0) that coincides with the start of the crank link, as shown in Figure 4.

The graphical interface is shown in Figure 5, it uses dialog boxes for data acquisition and for the display of the results, and the left side of the window shows the two-dimensional graph of the mechanism in study. In summary, a window displays: i) the mathematical solution of the mechanism, ω_{AB},ω_{BC}, R_3 and R_4. ii) The graphic representation of the solved mechanism. In this same window, you can return to the start window to make the selection of another possible case, as shown in Figure 5 [5-6].

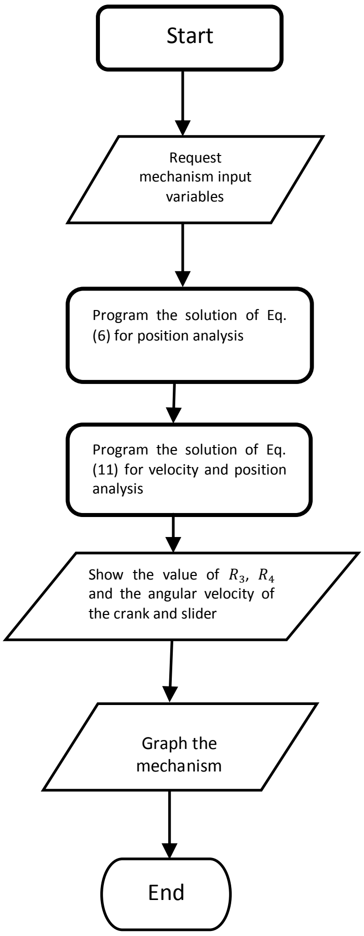

Figure 3 - Flow diagram of the program developed for position analysis of the four-bar mechanism

```
m3x=[p3(1)-(L2/8)];
m3y=[p3(2)-(L2/8)];

m4x=[p3(1)+(L2/8)];
m4y=[p3(2)-(L2/8)];

fill([m1x m2x m4x m3x], [m1y m2y m4y m3y],[0.3010 0.7450 0.9330])

c1x=[p3(1)-(L2/8)];
c1y=[p3(2)+(L2/8)+(L2/7)];

c2x=[p3(1)-(L2/8)-(L2/7)];
c2y=[p3(2)+(L2/8)+(L2/7)];

c3x=[p3(1)-(L2/8)-(L2/7)];
c3y=[p3(2)-(L2/8)-(L2/7)];

c4x=[p3(1)-(L2/8)];
c4y=[p3(2)-(L2/8)-(L2/7)];

fill([c1x c2x c3x c4x], [c1y c2y c3y c4y],[0.4660 0.6740 0.1880],[m1x m2x m4x m3x], [m1y m2y m4y m3y],[0.3010 0.7450 0.9330])
%fill([m1x m2x m4x m3x], [m1y m2y m4y m3y],[0.3010 0.7450 0.9330])

%a continuación viene la línea para la tierra
line([p3(1)-(L2/8) p3(1)-(L2/8)], [p3(2)-(L2/8)-(L2/7) p3(2)+(L2/8)+(L2/7)], 'Color','black', 'LineWidth', 2);
crank=line([p1(1) p2(1)], [p1(2) p2(2)], 'Color','red', 'LineWidth', 5);
arm=line([p2(1) p3(1)], [p2(2) p3(2)], 'Color','blue', 'LineWidth', 5);

grid on
```

Figure 4 - Code created for the layout of the crank-slider mechanism

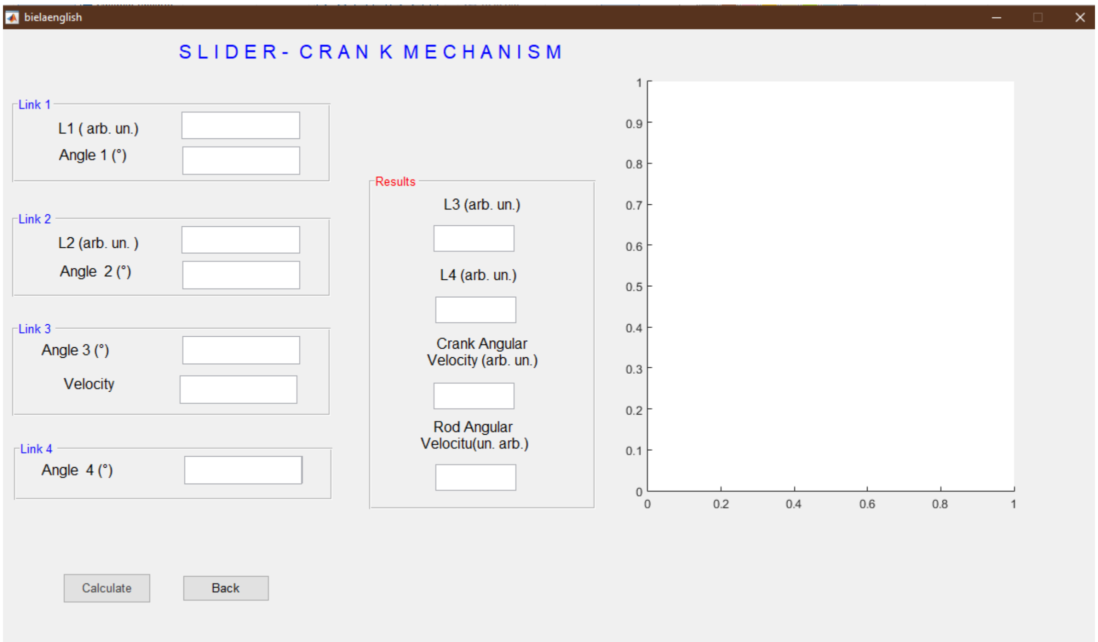

Figure 5 – Matlab GUIDE used for the analysis of the crank-slider mechanism

III. RESULTS AND DISCUSION

First, a test of a crank-connecting rod-sliding system was performed with the data shown in Table 1. The values have arbitrary units to be more general with respect to the measurement system used, velocity of the sliding mechanism for the first case has a negative value, which implies that it moves linearly downwards.

Table 1 – Test data

Link	Length (Arb. Unit)	Angular position (°)	Linear velocity (Arb. Unit)
Crank	0.5	45	---
Rod	1.5	0	---
Slider	Unknown	270	1.06
4	Unknown	180	----

The graph obtained by entering the data from Table 1 is shown in Figure 6.

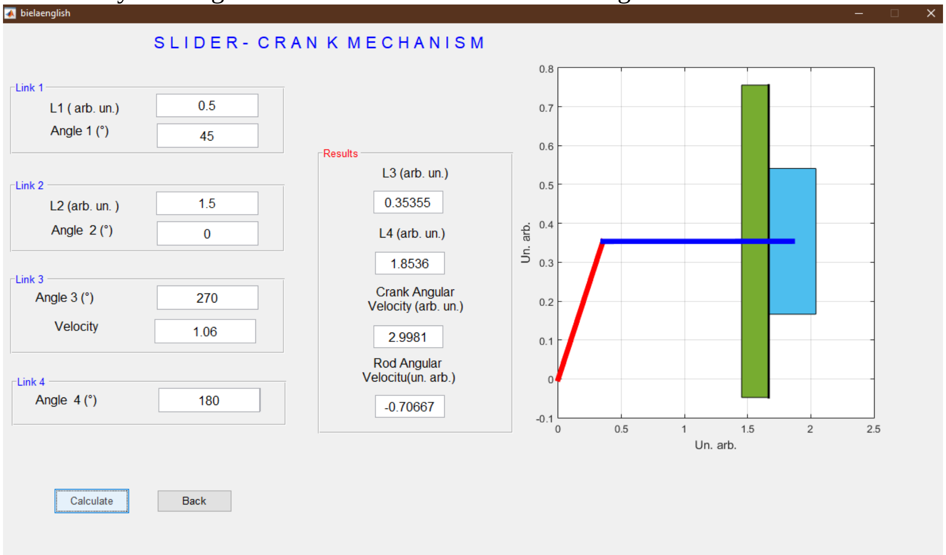

Figure 6 - Results obtained with the data in Table 1

IV. CONCLUSION

An application was developed and implemented in the GUIDE environment of MATLAB, in order to perform the mathematical and graphic analysis of the position and speed of a crank-slider mechanism and implement it in the teaching process in the study of mechanisms. The program calculates the lengths of the missing links and the angular velocity of the crank and connecting rod depending on the size and angular position of the crank and connecting rod and the speed of the slide. The developed program can help students in the mechanical engineering area strengthen their learning of mechanisms kinematics.

REFERENCE

[1]. S. Bureerat and S. Sleesongsom, “Constraint handling technique for four-bar linkage path generation using self-adaptive teaching–learning-based optimization with a diversity archive,” Eng. Optim., vol. 0273, 2020.
[2]. W. Y. Lin, “A GA-DE hybrid evolutionary algorithm for path synthesis of four-bar linkage,” Mech. Mach. Theory, vol. 45, no. 8, pp. 1096–1107, 2010.
[3]. S. Sleesongsom and S. Bureerat, “Four-bar linkage path generation through self-adaptive population size teaching-learning based optimization,” Knowledge-Based Syst., vol. 135, pp. 180–191, 2017.
[4]. C. Zhou, H. Chen, and L. Luo, “Students’ perceptions of creativity in learning Information Technology (IT) in project groups,” Comput. Human Behav., vol. 41, pp. 454–463, 2014.
[5]. D.J.Highman, N. Highman , "Matlab Guide." SIAM (2016).
[6]. MATLAB: Building GUIs with MATLAB. Manual (1996).

Yael Valdemar Torres Torres, et. al. "Analysis of the position and velocity of a slider-crank mechanism." *The International Journal of Engineering and Science (IJES)*, 9(12), (2020): pp. 61-65.