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Velocity Analysis of a Slider Crank Mechanism for Delta Robot Arm Manipulation: A Computational Approach

Akobuche Chikezie

Department of Mechanical/Mechatronics Engineering, Faculty of Engineering, Federal University Otuoke. P.M.B. 126, Yenagoa, Bayelsa State, Nigeria.
Corresponding Author email: chikezieaa@fuotuoke.edu.ng

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Abstract: *In this research, a velocity analysis of the slider crank mechanism's (SCM) for the delta robot arm manipulation was carried out. For the slider crank mechanism, new velocity response models were created. Trigonometric and inverse trigonometric functions are used in the novel Akozietic mathematical method, which is appropriate for kinematic analysis of intricate mechanisms like the four-bar mechanism (slider crank). The equilibrium conditions of the forces in a four-bar mechanism are used in the Akozietic mathematical technique to create simple mathematical models that enable user-written computer programs in Matlab and other programming languages. According to the velocity profile, the mechanism is under the most stress when the crank angle exceeds 300°, and the velocity is lowest at 180° and 0°.The crank angles where the slider shifts direction are the locations where the velocity passes zero. The novel mathematical procedure created in this study outperformed the other two kinematic analysis methods that were currently in use, according to a comparison of spreadsheets and this new mathematical method for mechanism analysis (Akozietic) with standard numerical solutions completed in Mathematica.*

Keywords: velocity analysis; slider-crank mechanism; robot arm; kinematic analysis; mathematical formulation

INTRODUCTION

The design of machine parts and many other engineering systems still relies heavily on the idea that SCM converts rotational motion into linear motion. The SCM is used by a variety of devices, including compressors, hand pumps, feeders, crushers, punches, injectors, diesel and gasoline internal combustion engines, and steam engines [4, 9, 11]. Machines have advanced significantly throughout history, altering how humans perform work and engage with the outside world. Examples of human inventiveness and progress can be found in everything from early human-made rudimentary machines like pulleys or levers to more complex modern technologies like robotics. According to Natesan (1994)[17], "Mechanism," a device that transforms one kind of motion into another, is the essential element at the core of all these machines, no matter how simple or complicated.

According to Abbas (2013) [1] and Oladejo et al. (2020) [21], a mechanism is a system made up of linked moving pieces that have particular relative motions and cooperate to form a structured body. Mechanisms are crucial parts that enable machines to move, lift, and communicate with their environment. In many engineering applications, mechanisms are used to generate fixed motion [3, 6, 10].The planar four-bar system is one such mechanism. Three moveable links, one fixed link, and four pin joints—referred to as members—make form a four-bar mechanism [4, 21]. It is a crucial connection structure that is necessary to achieve precise and regulated movements.One kind of four-bar system that may simultaneously execute rotational and linear motion is the slider crank mechanism. A four-bar linkage design is another name for it [5, 6]. The sliding block, connecting rod, and crankshaft are its key parts. It works by translating the crankshaft's rotational motion into the slider block's translational motion [3, 27].

The mechanism of operation involves transforming the crankshaft's rotational motion into the slider block's translational motion [24, 25, 26]. A four-bar linkage design is another name for it [16, 20]. The sliding block, connecting rod, and crankshaft are its key parts. It works by translating the crankshaft's rotational motion into the slider block's translational motion [15, 18]. One of the most practical mechanisms in contemporary internal combustion engines and a wide range of other applications, including robotics, pumps, suspension systems, and compressors, is the slider crank mechanism [17, 22].

Robot arms are designed and built using the slider-crank mechanism, which is renowned for its ease of use and effectiveness. Because of their adaptability and versatility, these arms—which are outfitted with complex mechanisms—are essential in a wide range of applications across multiple sectors.In recent decades, robots with built-in flexibility have evolved in an effort to match or surpass human agility and efficiency in performing activities involving motion and manipulation [14, 23]. Robots with inherent flexibility have evolved in recent decades in an effort to match or surpass human agility and efficiency in motion and manipulation tasks [2, 7]. Furthermore, robot arms help sectors that use automation—from manufacturing, assembly lines, welding, healthcare, and space exploration to other uses where flexibility and dexterity are critical—be more productive, efficient, and economical.

With a hand or end-effector fastened to one end and secured to the ground, a robot arm is made up of a flexible chain of links joined by joints [8, 12]. Another definition of a robot arm is a type of manipulator that is frequently programmable and performs tasks that are comparable to those of a human arm. Joints connecting its links allow either rotational (articulated) or linear (translational) motion. Jorge et al. (2018) [13] and Enaiyat et al. (2011) [11]. Their importance stems from their capacity to replicate the range of motion of a human arm, which makes them ideal for jobs involving intricate movements and accuracy.

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A mechanism's kinematic analysis examines how its linkages move without taking into account the forces behind that motion. [8, 12]. Since the days of labor-intensive calculations and cumbersome instruments, kinematic analysis of mechanisms has advanced significantly. Nowadays, computational analysis is essential for comprehending how mechanisms move, especially when it comes to four-bar linkages, which are used in many different fields. This method is more accurate and efficient, enabling a more thorough investigation of the behavior of mechanisms, which will result in additional advancements in their construction and functionality.

The significance of this study is underscored by the growing significance of slider-crank systems in contemporary industrial and technical contexts. In order to meet the changing needs of industries adopting automation, useful data and information that can improve the performance and adaptability of mechanical and mechatronic systems are needed.With the help of computational analysis, a useful technique in modern engineering, we may produce data to examine this mechanism's movements. Kinematic analysis of mechanisms has been done using a variety of techniques, including spreadsheets and commercial kinematic analysis software. It gets harder to evaluate mechanisms using these techniques as they get more complicated.

Therefore, this work presents a novel mathematical technique called Akozietic, which uses trigonometric and inverse trigonometric functions that are appropriate for the velocity analysis of intricate machinery in order to create simple mathematical models that enable user-written computer programs in Matlab and other programming languages, the Akozietic mathematical method for a four-bar mechanism makes use of the equilibrium conditions of the forces in the mechanism.standard numerical solutions carried out in Mathematica are compared and contrasted using spreadsheets and this novel mathematical approach for mechanism analysis (Akozietic). In order to design a pick-and-drop robot arm, the goal of this work is to calculate reasonable and reliable data for the velocity analysis of a slider crank mechanism without the need for complex mathematical procedures.

Formulation of the Velocity of the Sider Crank Mechanism

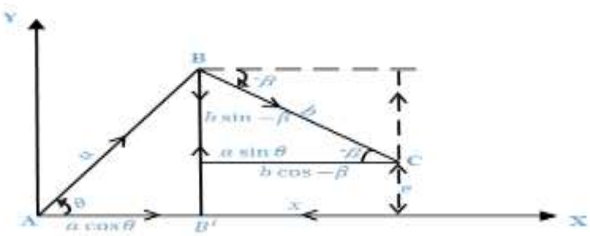


Fig 1: Kinematic Diagram of Slider-Crank Mechanism

Velocity Analysis of Slider Crank Mechanism

$\omega_1 =$ Angular velocity of the crank, $AB = \frac{d\theta}{dt}$

$\omega_2 =$ Angular velocity of the connecting rod, $BC = \frac{d\beta}{dt}$

$V_s =$ Linear velocity of the slider, $\frac{dx}{dt}$

Differentiating eqn.1 with respect to time,

$$bx - \sin\beta \times \frac{d\beta}{dt} = \frac{dx}{dt} - ax - \sin\theta \times \frac{d\theta}{dt}$$

$$-a\omega_1 \sin\theta - b\omega_2 \sin\beta - \frac{dx}{dt} = 0 \quad (1)$$

Again differentiating eqn.3 with respect to time

$$b\cos\beta \times \frac{d\beta}{dt} = -a\cos\theta \times \frac{d\theta}{dt}$$

$$a\omega_1 \cos\theta + b\omega_2 \cos\beta = 0 \quad (2)$$

$$-a\omega_1 \sin\theta\cos\beta - b\omega_2 \sin\beta\cos\beta - \frac{dx}{dt} \times \cos\beta = 0 \quad (3)$$

$$a\omega_1 \cos\theta\sin\beta + b\omega_2 \cos\beta\sin\beta = 0 \quad (4)$$

Adding eqn.11 and eqn.12

$$a\omega_1(\sin\beta\cos\theta - \cos\beta\sin\theta) - \frac{dx}{dt} \times \cos\beta = 0$$

$$a\omega_1 \sin(\beta - \theta) = \frac{dx}{dt} \times \cos\beta$$

$$\therefore \frac{dx}{dt} = \frac{a\omega_1 \sin\beta - \theta}{\cos\beta} \quad (5)$$

From this equation, the linear velocity of the slider (V_s) may be determined.

The angular velocity of the connecting rod *BC* (i.e., ω_2) may be determined from eqn.10 and it is given by

$$\omega_2 = \frac{-a\omega_1 \cos\theta}{b\cos\beta} \quad (6)$$

From this equation, the linear acceleration of the slider (a_s) may be determined.

The angular acceleration of the connecting rod, BC i.e ($\propto_2$) may be determined from eqn.16 and it is given by

$$\propto_2 = \frac{a(\propto_1 \cos\theta - \omega_1^2 \sin\theta - b\omega_2^2 \sin\beta)}{\text{b}\cos\beta} \quad (12)$$

Pseudocode Algorithm for the Velocity of the Slider Crank Mechanism

1. Initialize constants:
   - Set link lengths *a* (crank length) and *b* (connecting rod length).
   - Define the eccentricity length, *e*, initial crank angle, *θ*, and initial angular velocity, .
2. Loop through crank angles:
   - For each crank angle θ
     1. Compute β

        Use the equation for β

        $$\beta = sin^{-1}(\frac{e - asin\theta}{b})$$

     2. Calculate linear velocity Vs
        - Using the equation for Vs

          $$\frac{dx}{dt} = \frac{a\omega_1 sin\beta - \theta}{cos\beta}$$

     3. Compute angular velocity of the connecting rod ω_2

        Use the given formula for ω_2

        $$\omega_2 = \frac{-a\omega_1 cos\theta}{bcos\beta}$$

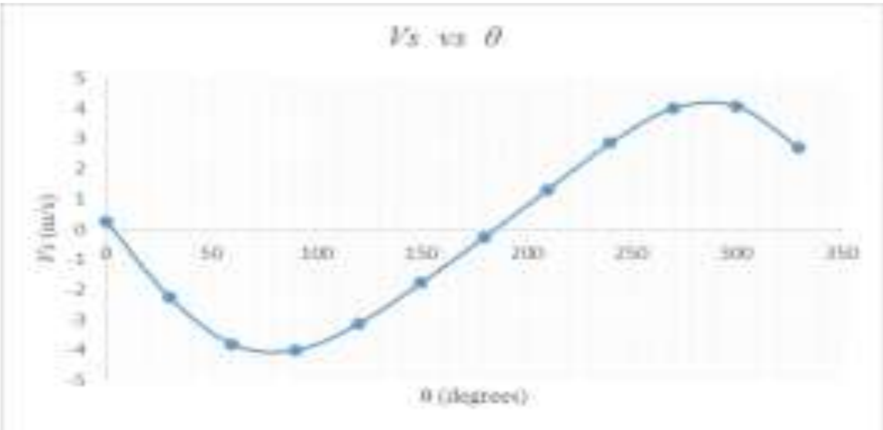
     4. Store values of Vs and ω_2
3. End loop:
   - Repeat the process for all crank angles.
4. Plot results:

- Plot the linear velocity Vs versus the crank angle θ.
- Plot the angular velocity ω_2 versus the crank angle θ.

RESULTS AND DISCUSSION

This study compares three methods of mechanism analysis, to ascertain the effectiveness of the newly developed method. MATLAB simulations and Excel computations were used to plot the mechanism's behaviour, focusing on how the crank and slider move in relation to each other. The following inputs were used for the computation: a = 0.2m, b = 0.75m, e = 0.05m, ω_1 = 20rad/s, α_1 = 10rad/s². The spreadsheet's results were obtained using the MS Excel, The numerical solutions were obtained by solving previous equations for slider crank analysis using the NDSolve algorithm in Mathematica. The Akozietic was obtained by a user written program in Matlab. All the plots obtained proved that the new mathematical method (Akozietic) performed better than the previous methods (spreadsheet and numerical).**Velocity Profile of a Slider Crank Mechanism.**

Fig. 1 presents the velocity profile of the slider crank mechanism. Fig 1(a) and Fig 1(b) represents the linear velocity, v_s, and the angular velocity, ω_2 respectively.



(a) Linear Velocity

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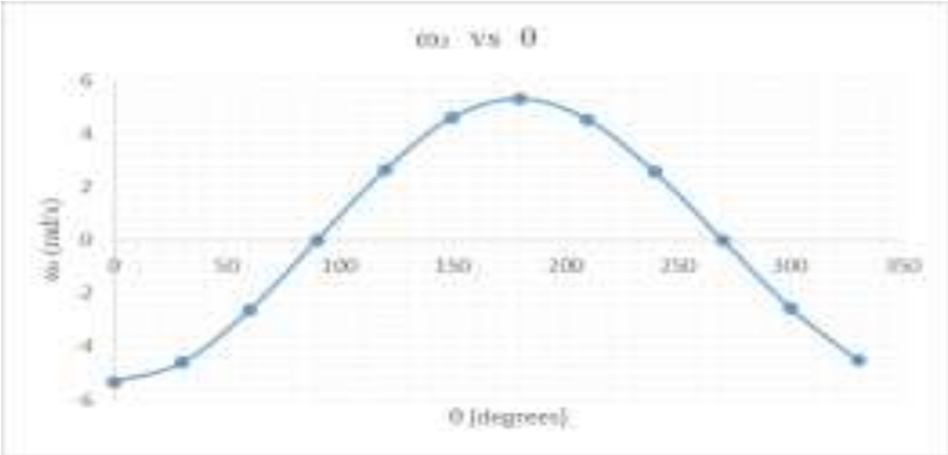


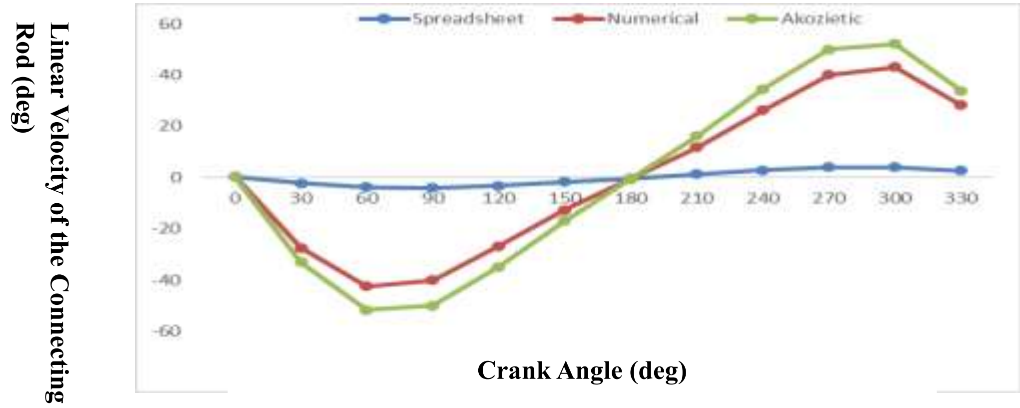
(b) Angular Velocity

Fig. 1: Velocity Profile of the Slider Crank (a: Linear Velocity, b: Angular Velocity}

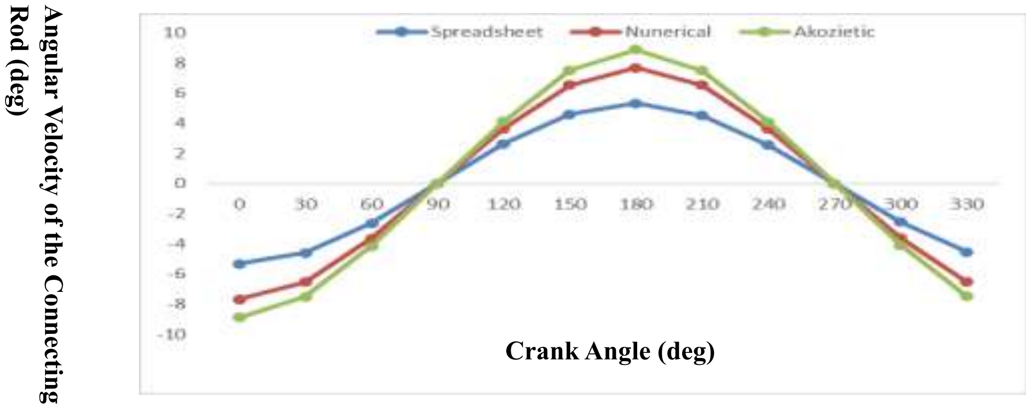
Fig. 1(a) shows the slider's linear velocity as a function of the crank angle. The oscillatory pattern indicates that the velocity is highest when the crank angle reaches 300°, this is where the mechanism experiences the most stress, and lowest at 180° and 0° (Obulesu & Krishna, 2019). The points where the velocity crosses zero correspond to the crank angles where the slider changes direction. Fig. 1(b) represents the angular velocity of the connecting rod. Similar to the linear velocity, the angular velocity varies non-linearly over the crank cycle, with its maximum velocity at 180° and its minimum at 90° and 270°.

3.2 Velocity Profile of a Slider Crank Mechanism.

Fig. 2 presents the velocity profile of the slider crank mechanism. Fig. 2(a) and Fig. 2(b) represent the linear velocity, v_s, and the angular velocity, ω_2 respectively. Fig. 2(a) shows the slider's linear velocity as a function of the crank angle. The oscillatory pattern indicates that the velocity is highest when the crank angle reaches 300°, this is where the mechanism experiences the most stress, and lowest at 180° and 0°. The points where the velocity crosses zero correspond to the crank angles where the slider changes direction. Fig. 4(b) represents the angular velocity of the connecting rod. Similar to the linear velocity, the angular velocity varies non-linearly over the crank cycle, with its maximum velocity at 180° and its minimum at 90° and 270°.



(a) Linear Velocity



(b) Angular Velocity

Fig. 4: Velocity Profile of the Slider Crank Mechanism(a:Linear Velocity and b: Angular Velocity)

Fig. 4(a) presents the velocity of the slider for different crank mechanism analysis methods. As the crank rotates, the velocity profile shows a dip between 50° and 150°, after which it starts rising again. The Akozietic method exhibited the highest peak velocities and also the lowest trough velocities. For the spreadsheet method as can be observed from Fig. 4 (a), the velocity values remain more contained, with a smaller peak and trough. Overall, larger link lengths result in greater slider velocity fluctuations, suggesting higher-speed performance for larger configurations. It is observed that, although the computational methods vary, yet, the three trends meet at particular points on the plot, these positions correspond to the dead centers (0°, 180°, 360°) where the slider changes direction, leading to minimal or zero velocity.

In Fig. 4(b), the angular velocity of the connecting rod for various methods is presented. Unlike the velocity profile of the slider, the Akozietic shows the highest peaks, while the spreadsheet represents the smallest angular velocities. Increasing the crank and rod lengths leads to a higher angular velocity at 180°. Akozietic method yielded higher rotational speeds, which may be beneficial or detrimental depending on the system's application. From Fig. 4(b) it is seen that, even with the variations in the analysis, the three trends meet at particular points on the plot, these points correspond to the mid-stroke (90°, 270°) where the rod aligns parallel to the crank, leading to minimal or zero velocity.

CONCLUSION

Comparison of spreadsheet and this new mathematical method for mechanism analysis (Akozietic) with standard numerical solutions performed in Mathematica revealed that the new mathematical process developed in this study performed better than the other two existing methods of kinematic analysis. the velocity profile shows a dip between 50° and 150°, after which it starts rising again. The Akozietic method exhibited the highest peak velocities and also the lowest trough velocities. For the spreadsheet method as can be observed from Fig. 5(a), the velocity values remain more contained, with a smaller peak and trough. Overall, larger link lengths result in greater slider velocity fluctuations, suggesting higher-speed performance for larger configurations. It is observed that, although the computational methods vary, yet, the three trends meet at particular points on the plot, these positions correspond to the dead centers (0°, 180°, 360°) where the slider changes direction, leading to minimal or zero velocity. The spreadsheet method remains comparatively flat, indicating lower fluctuations in acceleration, as this configuration has the smallest link lengths. Increasing the lengths of the crank and connecting rod amplifies the maximum acceleration of the slider, which implies greater forces will be exerted on the slider in larger configurations. The peak angular acceleration occurs at 90°, with Akozietic method showing the highest values due to the long crank and rod lengths. The spreadsheet method shows lower values, highlighting that smaller crank and rod lengths generate less angular acceleration.

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