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A DYNAMIC BEHAVIOUR OF SLIDER CRANK MECHANISM ANALYSIS

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Abstract: Motions of the various mechanism like acceleration, velocity, displacement and driven members involved the connection of rod and piston. The design of this rod and piston is known as kinematic analysis of the slider crank mechanism. This work used graphical method and analytical method of complex algebra method to analyse kinematic analysis of the engine. An experimental investigation was undertaken to study the variation of piston velocity with the crank angle of a slider crank mechanism, using the principle of instantaneous center approach. This phenomenon was also numerically modeled using the concepts of trigonometric and analytical geometry. But the numeric–calculation was sufficiently tedious, and prone to error, that led to developing a computer solution using Microsoft Excel Package. The three approaches generated piston velocity crank angle graph that were in good agreement with one another, from where it was observed that the variation resembles cosine curve rule, and that the maximum velocity of the slider occurs at a crank angle of 90° while the minimum occurs at 27°.
Keywords: slider–crank, mechanism, connecting rod, linear motion, piston velocity

1. INTRODUCTION

Mechanisms may be defined as the division of machine design, which is concerned with the kinematics design of linkages, cams, gear and gear trains. Kinematics design is the design on the basis of strength requirements. Combination of stable bodies structures which are linked together relative motion is known as mechanism. Slider–crank mechanism is widely used and finds its greatest application in the internal–combustion engine. Figure 1 shows a sketch in which link 1, link 2, link 3 and link 4 represents frame, crank, connecting rod and slider respectively. As in Internal combustion engine, link 4 is regarded as the piston which involves exertion of gas pressure with the aid of connecting rod that transmitted force to the crank. This application also occurs in air compressors in which electric motor drives the crank, which in turn drives the piston that compresses the air. The importance of crank slider mechanism is very important in manufacturing industries especially in rotary and translatory motion system. This work aimed to verify the appropriateness of using geometrical method and computer simulation method to study the characteristics of motion in slider crank mechanism.

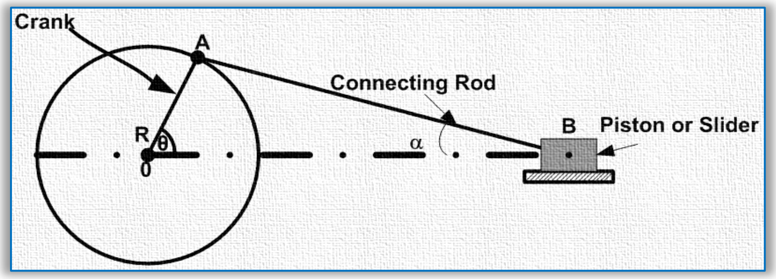

Figure 1. Slider Crank Mechanism

2. LITERATURE REVIEW

Vikas [1] and Oladejo et al. [2] stated that decrement in linear thrust force is common during expansion stroke, which brings about the frictional power. Nabil [3] and Morrison and Crossland [4] applied graphical method for two phases of the crank shaft and stated that the output from the graphical method, were compared with the results obtained from analytical and numerical method, with the acceptale result. The experiment was conducted with the crank shaft revolution at constant angular velocity in connection with time dependent of gas pressure force on the slider crank.

Desai [5] and Oladejo, et al. [6] presented paper on four stroke internal combustion engine, using analytical approach which is accurate and took short time when subjected to programming with computer solution. Hsin – Pao et al. [7] and Santosh, et al. [8] highlighted that the motion functions are obtained from the continuous crank acceleration when the crank were driven by many devices when slider – crank mechanisms used in open / close motion from toggle positions. A program was computed by Oladejo et al. [2]; Ryder and Bennett [9] and Darina, et al. [10] which was tested with motion mechanism parameters, the solution obtained from the program was compared with the manual calculations output. P value less than 0.05 were obtained which indicates that there is no differences between the computer program and manual calculations, which indicate the efficacy of the program.

When presenting an experimental verification from the simulated results of a slider crank mechanism of one clearane revolute joint, Haroun and Megahed [11] and Hannah and Stephens [12] proved that simulation result and experimental result and experimental result are close to each other.

Santosh, et al., [8], Oladejo and Koya [13] and Vaidya and Padole [14] worked on slider crank mechanism with bar linkage of both linear and rotational motion simultaneously, aiming to investigate kinematics and resulting dynamic force of the machine. The motion parameters generated during the operation was determined analytically as well as with computer programming method. Both methods gives the same result when comparing the magnitude of the shaking forces obtained.

Darina et al. [10], Steven [15] and Adekunle et al. [16] developed eccentric crank mechanism using ADAMS/ view software which follows complete kinematical analysis. The result obtained was compared with calculation experiment and evaluated, which also came up with results without any discrepancies. Jih–Lian et al. [17] and Mohammad et al. [18] the parameters of a slider crank mechanism was identified using real – coded genetic algorithm (RGA). The calculation is by using the real code by encoding and decoding operations. The efficiency of the calculation is acknowledged and the numerical simulations and experimental showed that the identified method is feasible.

Analytical technique provides general application and solution which can be used or all mechanism configuration, while graphical method relies on scale drawings for its configuration. It has three versions namely; instantaneous center, velocity diagram and acceleration diagram. Series of drawings are needed when presenting complete solution, while the analytical method entails many analysis, computation and calculus for simple mechanism which make it little tedious. As a result, this work developed computer to establish the dynamic behaviour of slider crank mechanism analysis, since this method removes several drawings involved in the graphical approach and laborious calculations in the analytical approach.

3. METHODOLOGY

The mode of operation of mechanism which involves slider – crank mechanism (reciprocating piston engine, reciprocating pump, internal combustion engine etc) were used to set up the methodology of the experiment. The experimental, analytical and simulation approaches were applied to verify the variation of piston velocities with the crank angular displacement. The experiment was conducted in form of mode of operation of any slider–crank mechanism.

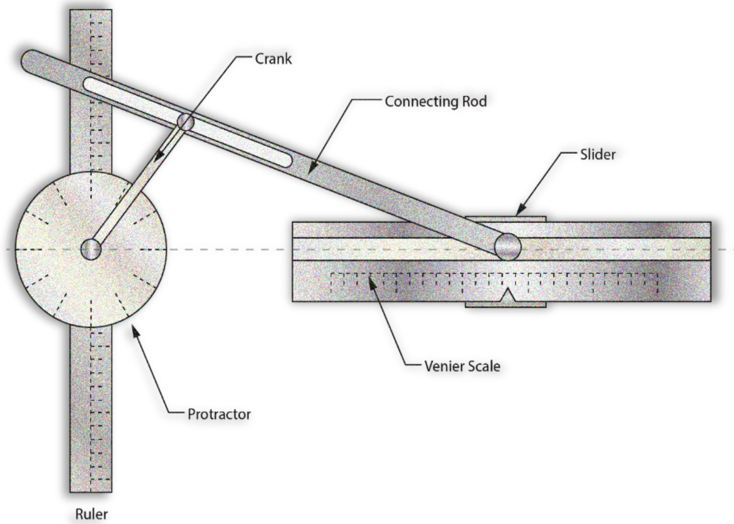

Figure 2. Slider–crank chain apparatus

Experimental Method

The experiment was performed by making use of slider–crank chain apparatus, made available at the Mechanics of Machines Laboratory. As the apparatus is illustrated in Figure 2, the crank was set, using the protractor, to an angle of 30° from the inner dead center position, and the distance from the crank center to the centerline of the extended connecting rod was recorded using the vertical scale [11, 19, 22].

For the position of the mechanism shown in figure 2, the instantaneous center of the connecting rod AB is at I_{AB} as shown in figure 3.

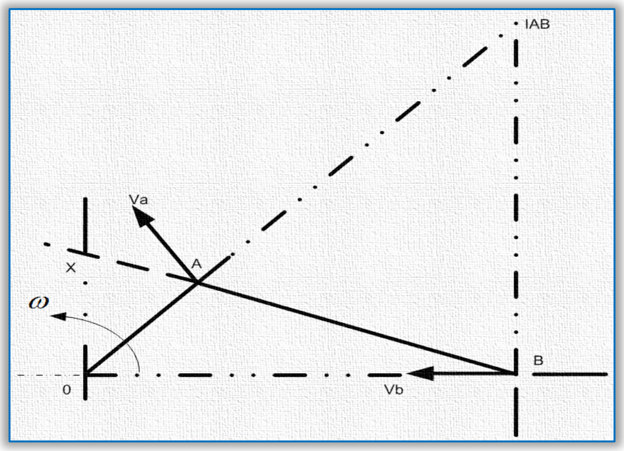

Figure 3. Instantaneous Center

Table 1. Experimental Results.

Crank Angle (Degree)	Distance OX (mm)	Slider Velocity (mm/s)
0	0.00	0.000
30	125	2500
60	200	4000
90	205	4100
120	155	3100
150	80	1600
180	0.00	0.000
210	–80	–1600
240	–155	–1300
270	–205	–4100
300	–200	–4000
330	–125	–2500
360	0.00	0.000

Refer to figure 3, Linear Velocity of A,

$$V_a = OA \times u \quad (1)$$

Assuming constant angular velocity of the crank, u = 1

$$V_A = OA \quad (2)$$

Since the connecting rod is instantaneous rotating about point I_{AB}

$$\frac{V_A}{I_{AB}A} = \frac{V_b}{I_{AB}B} \quad (3)$$

Piston Velocity,

$$V_b = \frac{V_a}{I_{AB}A}[I_{AB}B] \quad (4)$$

Triangles I_{AB} AB and OAX are similar

$$I_{AB}B/I_{AB}A = OX/OA \quad (5)$$

And since,

$$V_a = OA \quad (6)$$

Therefore,

$$V_B = \frac{OX}{OA}[OA] = OX \quad (7)$$

The result from the arrangements in figure 2 is represented in Table 1.

Numerical Calculation Method

Refer to slider–crank mechanism in figure 3; the slider is attached to the connecting rod AB of Length L. The crank OA, of radius a, rotates in anticlockwise direction with uniform angular velocity u rad/s. Let the crank makes an angle e with the axis and slider reciprocates along the part of x–axis. Equation for displacement, velocity, and acceleration of the slider were derived in (1), and stated below.

Linear displacement of the slider,

$$X = R\,(1 - \cos e) + \left(\frac{R^2}{2L}\right)\sin^2 e \quad (8)$$

Where **e** = ut because u is constant.

Linear velocity of the slider,

$$vb = \frac{dx}{dt} Ru\left[\cos e + \left(\frac{R}{L}\right)\sin(2e)\right] \quad (9)$$

Linear acceleration of the slider

$$ab = \frac{d^2x}{dt^2} = Ru^2\left[coe\ e + \left(\frac{R}{L}\right)\cos 2e\right] \quad (10)$$

Using the following parameters, generated from the slider–crank chain apparatus, in equation 9, the velocities obtained at varying angles of the crank are illustrated in Table 2:

- Radius of the crank, R (mm) = 200.
- Angular velocity of the crank, u (rad/s) = 20.
- Angle of the crank, (0° to 360° at an interval of 30°), and
- Length of the connecting rod, L (mm) = 750mm

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Simulation Method

Based on the mathematical expression in equation (9), a computer model was developed using Microsoft Excel and the result generated is illustrated in Table 2. Equation (9) was converted to an acceptable form for Ms–Excel computation as in (11) which output results were presented in Table 2

Vb = 200 * 20 * (SIN (RADIANS (A9))
+ (200/1500) * SIN (RADIANS (2*A9))) (11)

Table 2. Numerically Computed Results

Crank Angle (degree)	Velocity of the Slider (mm/s)	VOP
0	0.00	0.000
30	2461.88	2461.880
60	3925.98	3925.982
90	4000.00	4000.000
120	3002.22	3002.221
150	1538.11	1538.120
180	0.00	0.000
210	–1538.11	–1538.120
240	–3002.22	–3002.221
270	–4000.00	–4000.000
300	–3925.98	–3925.982
330	–2461.88	–2461.880
360	0.00	0.000

4. RESULTS AND DISCUSSION

Proper cross–examination and comparison of the tabulated output variables in Tables 1 and 2 illustrated that the two approaches produced the same results. That is the analytical approach has been used to confirm the accuracy of the simulated model. The experimental results obtained, as shown in Table 1, and that of simulated approach in Table 2 were plotted against the varying angles of the crank, as illustrated in Figure 4; and variation of the slider velocity with the crank angle was confirmed, by two methods, to resemble the behavior of cosine curve, as shown in Figure 4 also shows that the maximum velocity of the slider was obtained at the crank angle of 90°, while the minimum occurs at 270°.

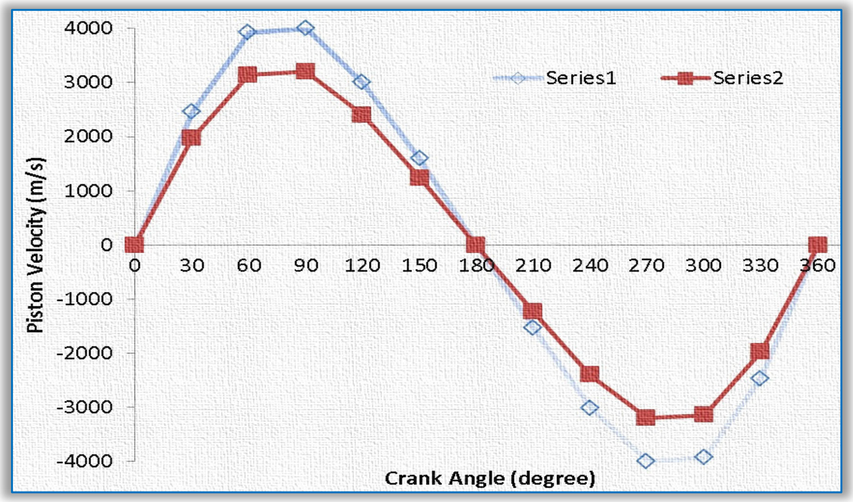

Figure 4. Comparison of the Results from Experimental and Simulated Approaches

5. CONCLUSIONS

Systematic operation of crank – slider was understudied and used to conduct the analytical experiment by numerical calculation and computer simulation method. This was done so that the simulated model accuracy could be confirmed. By using the computer simulated method, following benefits were derived:

- errors that are always creeping in on the course of graphical and analytical methods have been completely removed;
- In the graphical and analytical approaches, there is need for constructing or calculating the output variables at different positions of the crank, which are always tedious, time–consuming, labour–intensive, and prone to errors;
- The computer model generates all the output variables for all angular displacements of the crank between 0° and 360° at an interval of 30°;
- The computer model will reduce labour cost and increase productivity;
- Accuracy of output variables, from the model, is guaranteed all the time;
- The analysis can be done within a very short period; and
- There is also room for variation of input variables for proper study of the behavior of the mechanism under different conditions.

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The result of this work is in line with Shouguo and Shulin [20] and Oluwajobi et al. [21] when using Langrage equation in their numerical analysis of slider crank; also in conformity to the discoveries of Darina et al. [10], Steven [15] and Adekunle et al. [16]. In the light of the above conclusions, the following recommendations are made:

— there should be positive actions aimed at transferring research results to industrial use; and
— efforts should be made to extend this study to similar mechanisms like four bars and scotch yoke mechanism, and use of computer packages must be adequately encouraged as compared with most manual activities in mechanical workshops.

NOTATIONS

Ab	Linear acceleration of the slider, (mm/s^2)
IAB	Instantaneous Center
L	Connecting rod, (mm)
R	Crank radius, (mm)
Va	Velocity of the crank, (mm/s^2)
Vb	Linear Velocity of the Slider, (mm/s^2)
X	Linear displacement of the piston, (mm)
Ω	Crank angular velocity, (rad/s)
Ø	Crank angular displacement, (degree)
CA	Crank Angle, (degree)
VOP	Velocity of the Piston, (mm/sec)

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