

DEVELOPMENT OF A PROTOTYPE DEMO-SLIDER CRANK MECHANISM FOR DEMONSTRATION USING SOLIDWORKS

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Abstract: *The slider-crank mechanism converts rotary motion to reciprocating linear motion. It is the basic mechanism used in diesel and gasoline internal combustion engines, these machines play an indispensable role in modern technology. The aim of this was to design and construct a prototype of a slider-crank mechanism that is to be used for demonstration and instrumentation. The slider-crank mechanism was designed, a model of the design was created and simulated with the use of SolidWorks and the simulated results were used to construct a wooden prototype of the slider-crank mechanism. Experimental results were obtained from the prototype by measuring the slider displacements and velocity for a crank angle of 0° to 360° in the clockwise direction at angular intervals of 30°. Analytic results were obtained with the use of MATLAB. The analytic and experimental results were then compared statistically by obtaining their percentage error.*

Keywords: *mechanism, slider-crank, design, percentage error, solidworks, MATLAB*

1. INTRODUCTION

The slider-crank mechanism is a particular four-bar linkage configuration that converts linear motion to rotational, or vice versa. Internal combustion engines are a common example of this mechanism, where combustion in a cylinder creates pressure which drives a piston. The piston's linear motion is converted into rotational motion at the crank through a mutual link, referred to as the connecting rod. As the geometry of the crank forces the conversion of linear motion to rotational, shaking forces are generated and applied to the crank's housing. These shaking forces result in vibrations which impede the operation of the engine. Jomartov, et al., (2015), Veg, et al., (2015), criterion of optimization of the dynamic synthesis of a machine is the root mean square sum of the moments of driving forces, the forces of resistance and inertia forces which are reduced to the axis of rotation of the crank. The method of optimal dynamic synthesis of a machine can be used in the design of new and the improvement of known mechanisms and machines. Patel, (2013), study of these slight variances produces useful insight. The following report details the successful design, fabrication and testing of a pneumatically powered slider crank mechanism for the purpose of classroom demonstration and experimentation. Transducers mounted to the mechanism record kinematic and dynamic force data during operation, which can then be compared to analytical values. Thanh-Phong and Shyh-Chour, (2014); Hroncová, et al., (2016); means of mathematic models, the kinematic behaviors of the flexible slider crank mechanism are captured using MATLAB software. Finite element analysis (FEA) is used to show the stress distribution. Saad, et al., (2009), study involves integrating a dynamic model of the slider-crank mechanism into a wear prediction procedure. The prediction procedure builds upon a widely used iterative wear scheme. The accuracy of the predictions is validated using results from an actual slider-crank mechanism. Babu and Subbaratnam, (2015), the analytical method is used to define the various position of the crank and respective position of slider in Slider Crank mechanism is studied. MATLAB programs are provided for kinematic analysis of a Slider Crank mechanism that contains a coupler point. The MATLAB program performs position, velocity, and acceleration analysis for a given angle of the crank or for a given input. Assad, (2012), simulations were performed with different time steps and durations. The friction was assumed to be negligible during these simulations. As a result of this work, the longitudinal response of the slider block is observed with applied moment as well as slider block response along with reaction forces at joint R2 is investigated in case of imposed rotational motion.

Mohammad, et al., (2011), results of initial researches show that an important reason of these parts' damaging is using of downshifting in driving. In this research, we are concerned on the analysis of kinematics and kinetic of slider-crank mechanism of the engine in maximum power, maximum torque and downshifting situation. Oke and Okunlola, (2015), Darina, et al., (2012), Rita, et al., (2013), used the FORTRAN computer program for the analytic synthesis of the Slider-Crank mechanism, the kinematic equations were converted into a computer program that could provide result for a given parameter. This method was less time consuming, however, it still did not solve for collision of components.

Samba and Alagala, (2014), the reports of the results are in numerical form. The analysis based on the mathematical model performed with the help of MATLAB. It is, usually, found in reciprocating steam engine mechanism. This type of mechanism converts rotary motion into reciprocating motion and vice versa (Khurmi, 2009). The slider crank mechanism is the basic mechanism used in most engines (Mohammad, *et al.*, 2010). Owing to this, vigorous work has been done and some methods have been adopted to solve the problem. Patel, (2013) itemized the methods of kinematic analysis of Slider-Crank mechanisms as: Analytic method, graphical method and Computer Aided Method. Khurmi, (2009) preferred the analytical method of relative velocity in the kinematic analysis of Slider Crank mechanisms. Jack, (2013); Oladejo and Adetan, (2012); used the method of spreadsheet to determine the parameters of the slider-crank mechanisms for optimum linkage dimensions and speeds. This method provided plots and graphs that was used to vary the parameters of the linkages with respect to the load, positions and speeds. This method did not account for bearing friction and contact between linkages. Jomartov, (2015), developed a method of optimal dynamic synthesis of a machine using slider crank mechanism using the root mean square criterion to sum the moments of the driving forces. This method, however, assumed that all other equations guiding the mechanism are specified.

Han, *et al.*, (2014), synthesis method which simultaneously satisfied the conditions of time ratio and minimum transmission angle was presented. This method helped to avoid iterations and checking during the design process. Nikravesh (2012), made use of Newton-Raphson method for solving the complex algebraic equations obtained during the synthesis of Slider-Crank mechanisms, this method, however, required advanced knowledge in mathematics and was found to be difficult when used to analyse more complex mechanisms. Ming-Shyan, *et al.*, (2010), compared the results of mathematical modelling of slider-crank mechanisms to actual experimental results and found analytic method to be very accurate. Regarding the use of Computer Aided method of design, Mohammad, *et al.*, (2010), made use of ADAMS/Engine for the kinematic analysis of slider crank mechanisms in the Otto-engine of Nissan Z24 cars during downshifting conditions while Darina, *et al.*, (2012) made use of MSC Adams/View for their analysis, the results obtained were found to correlate with those obtained when they used analytic method.

Babu, (2015), and Samba, et al., (2014) compared the results obtained from the use of CATIA and MATLAB during the synthesis of mechanisms, the results correlated with little error. *Hamilton's principle, Lagrange multiplier, geometric constraints*, partitioning method and *Baumgartner Stabilization Method (BSM)* were employed by Ming-Shyan, *et al.*, (2010) to derive the dynamic equations of a spatial slider-crank mechanism, it was observed that the parameters of a mechanical system could not be measured directly, if the system cannot be taken apart. This paper demonstrates the application of theory to mechanism synthesis and analysis; formulates a dynamic simulation model of slider crank mechanism using MATLAB and Solid Works software and finally, production of a model for instrumentation.

2. MATERIALS AND METHODOLOGY

2.1 Input Parameters: are the input parameters for the design of the slider-crank mechanism,

- Crank radius, r
- Connecting rod length, l : for a given slider crank mechanism, the connecting rod length is related to the crank radius by the formula shown below, (Jack, 2013),

$$\frac{r}{l} \leq \frac{1}{3} \quad (1)$$

- Crank angle, θ .
- Crank speed ω : this is dependent on the motor selected for the mechanism. A crank speed of 111rpm was chosen based on the most suitable electric motor available in the market.

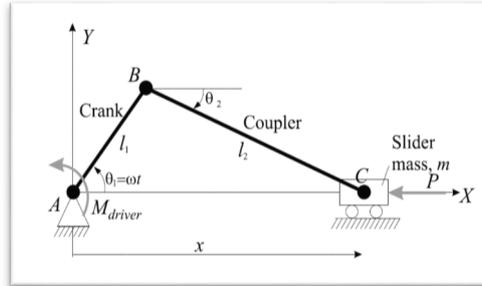


Figure 1: Slider-Crank Mechanisms

Output Parameters

Stroke: this parameter is related to the crank radius by the formula shown below

$$S = 2r \quad (2)$$

Calculations for Obtaining Design Parameters

From figure 2 above, equations 3 and 4 hold true for any given value of θ and β (Desai, 2009):

$$r \cos \theta + l \cos \beta - R = 0 \quad (3)$$

$$r \sin \theta - l \sin \beta = 0 \quad (4)$$

Also given that:

$$R_{max} = \phi L \quad (5)$$

Where,

$$L = 500mm \text{ (intuitive)}$$

$$R_{max} = 0.5 * 500mm = 250$$

Also, from the figure above, when $R = R_{max}$; $\theta = 0^\circ$; $\beta = 360^\circ$

Hence, from equation (2) above:

$$r + l - R = 0; \quad (6)$$

Approximately from equation (1),

$$l \geq 3r \therefore r + 3r - 250mm = 0$$

$$r = \frac{250}{4}mm = 62.5$$

For construction reasons, $r = 70mm$

Similarly: $l \geq 3r \therefore l \geq 3 * 70 \geq 210mm$

Also for construction reasons, $l = 273mm$.

Stroke, $S = 2r = 140mm$

The value of the stroke was used to determine the length of the slide rail.

2.2 Material Selection

The material that was chosen for the prototype to be built was wood due to the following reasons:

- Economic reasons: wood is a cheaper material and is readily available thus making it easy to procure for the purpose of the project.
- Practical reasons: wood is light in weight making it more portable than metal. Portability is a major requirement for the prototype that was to be constructed, and
- Engineering reasons,

$$\tau = \frac{16T}{\pi d^3}, \text{ (Khurmi, 2009):} \quad (7)$$

From the design data: $T = T_{motor} = 2.5Nm$; $d = 35mm$

$$\tau_{ut} = 16 * \frac{2.5}{\pi * 0.035^3} = \tau_{ut} = 0.3MPa$$

But $\tau_y = 9MPa$ for iroko wood; (David, 2010)

$$\tau_y \gg \tau_{ut}$$

This means that the material will not fail, hence, wood satisfies the design criteria for maximum shear stress.

2.3 Prototype Development Process Using Solidworks

SolidWorks is mechanical design automation software that takes advantage of the familiar Microsoft Windows graphical user interface. This easy-to-learn tool makes it possible for mechanical designers to quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings. This *Getting Started* book discusses some basic concepts and terminology used throughout the SolidWorks application. It provides exercises to familiarize you with creating parts, drawings and assemblies, and introduces some of the most commonly used features of the SolidWorks mechanical design automation system.

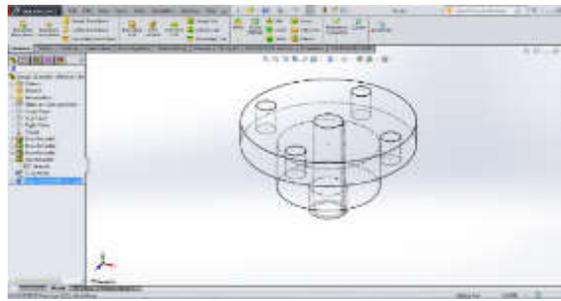


Figure 2: Wireframe view of flange

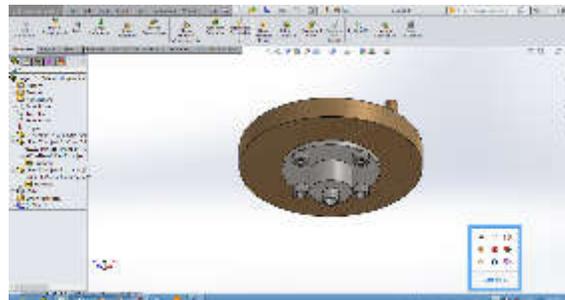


Figure 3: Solid model of flange and crank

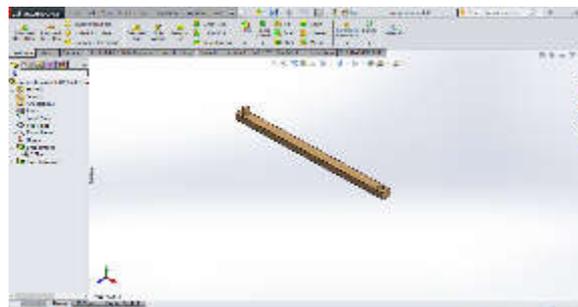


Figure 4: Solid model of connecting rod

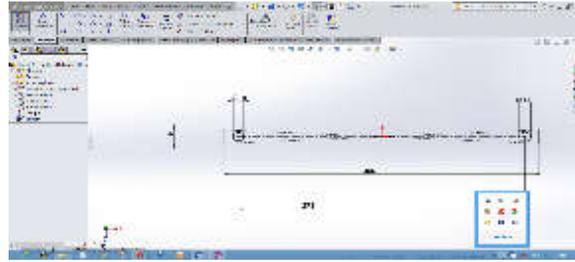


Figure 5: Sketch of connecting rod

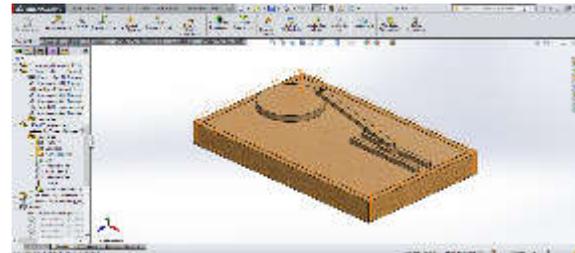


Figure 6: Solid model of slider

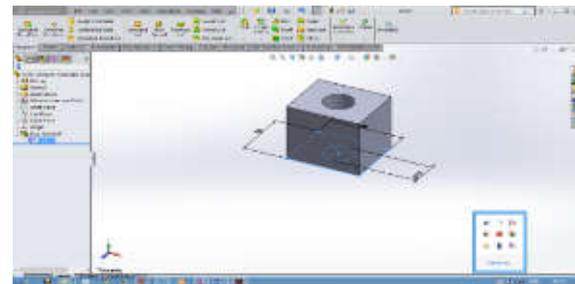


Figure 7: Sketch of Slider

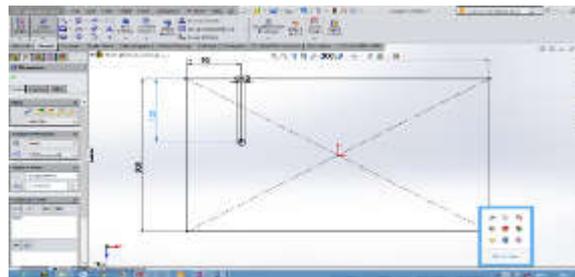


Figure 8: Sketch of base

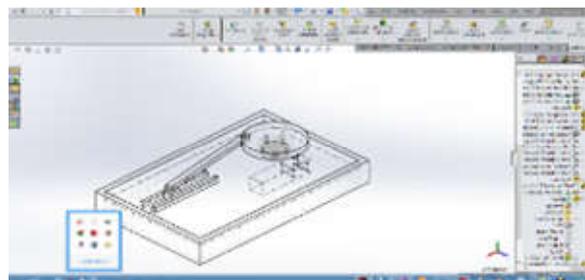


Figure 9: 3D model of base

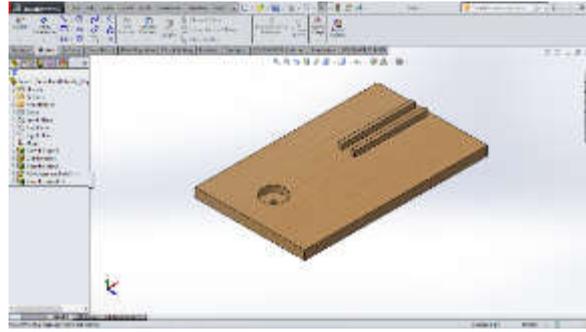


Figure 10: Wireframe model of full assembly

2.4 Method of Analysis Employed

The following methods of data collection and analysis were applied during the course of the project:

- Direct measurement from the prototype constructed: this was done after the assembly of the prototype, the angular displacement of the crank and the corresponding linear displacement given were measured and the values were recorded. The graph of linear displacement of the slider against the angular displacement of the crank was then plotted with the use of MATLAB.
 - Analytical approach using SolidWorks Simulation and: this was done as shown below;
- The following were the governing kinematic equations used to generate the results for the slider-crank mechanism that was constructed:

- Crank speed:

$$\omega = \frac{2\pi N}{60} \quad (9)$$

- Slider position with respect to the crank angle:

$$x(\theta) = l - \frac{r^2}{4l} + r \left(\sin\theta + \frac{r}{4l} \sin 2\theta \right) \quad (10)$$

- Slider velocity with respect to the crank angle:

$$V(\theta) = \omega r \left[\cos\theta + \frac{r}{2l} \cos 2\theta \right] \quad (11)$$

- Slider acceleration with respect to the crank angle:

$$A(\theta) = -r\omega^2 \left(\sin\theta + \frac{r}{l} \sin 2\theta \right) \quad (12)$$

The following values were the constants of the above equations:

- $r = 70\text{mm}$ or 0.07m ,
- $l = 273\text{mm}$ or 0.273m
- $\omega = 11.6 \text{ rads/s}$

Statistical analysis: analytical results were compared with the graphical results using the percentage error represented by the formula:

$$\%error = \frac{error}{expected\ value} * 100\%$$

3 RESULTS AND DISCUSSION

The displacement (x), velocity (v) and acceleration (a) of the slider were obtained analytically with the use of equations (10), (11), and (12) respectively. The aforementioned equations were solved with the use of MATLAB over angular increments of 30 degrees. The maximum and minimum readings were observed to fall at 0° and 180° respectively.

Figure 10: The relationship between the slider displacement from the crank center measured in meters and the crank angular displacement measured in radians as plotted with the use of MATLAB.

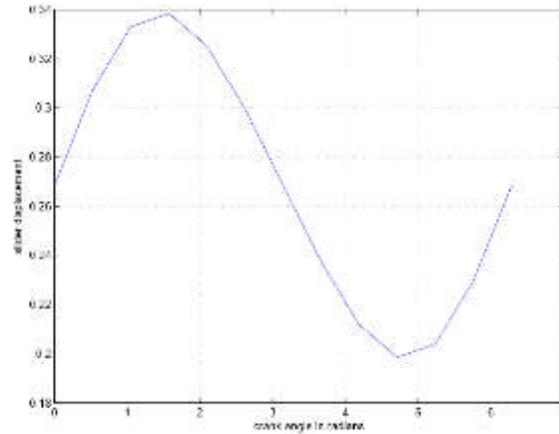


Figure 10: The relationship between the speed of the slider and the change in the crank angle.

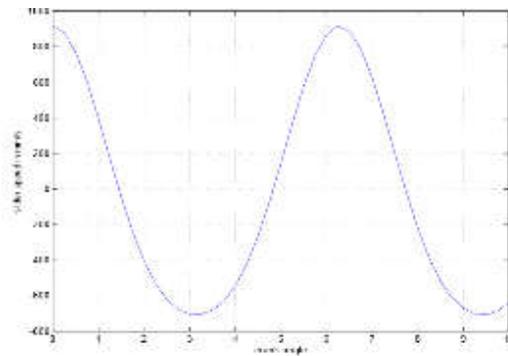


Figure 11: The relationship between the speed of the slider and the change in the crank angle.

Figure 12 shows the relationship between the slider displacement and the time that elapsed during the motion simulation that was performed with the use of SolidWorks, the slider displacements were measured with respect to the axis of the base rather than the axis of the crank, this brought about an offset as seen in point A in figure 12.

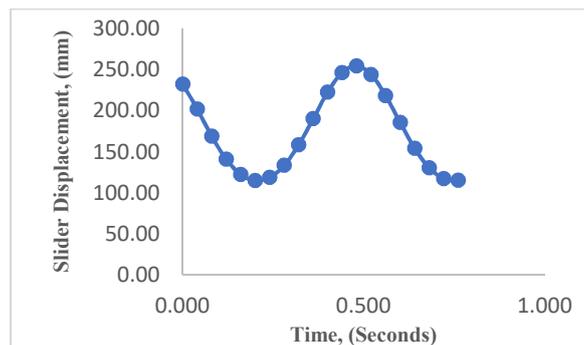


Figure 12: The relationship between the Speed of the slider and the time elapsed

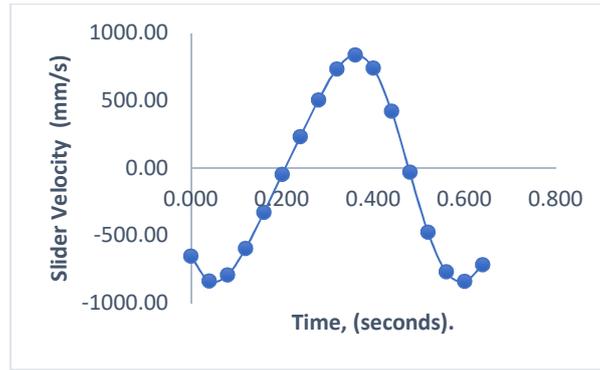


Figure 13: Slider velocity against time from motion simulation.

The measured values for slider displacements obtained from the prototype (X) and that of x representing the values of slider displacement that were obtained analytically with the use of MATLAB were compared as shown in figure 14. It shows the relationship between the measured slider displacement from the prototype and the analytic values obtained with the use of MATLAB, it can be seen from the figure 14 that both curves follow the same sinusoidal path and the maximum and minimum values of both curves coincide at the same angular displacements.

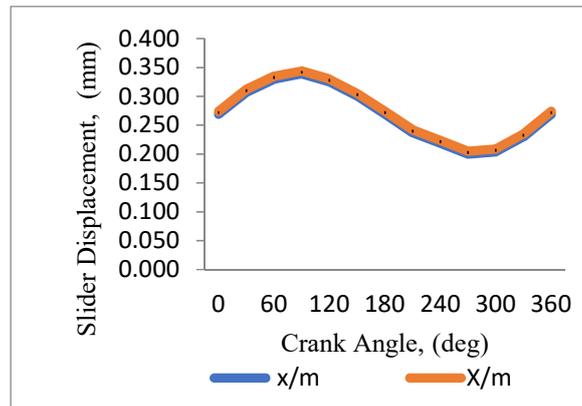


Figure 14: Comparing practical to analytical values of displacement.

3.2 Discussion of Results

In General, the experimental results compared well with the analytical results. There were some inconsistencies due to differences in real world operation versus theoretical operation, as well as some degree of error introduced by the instrumentation methods and the construction of the prototype. The results obtained analytically with the use of MATLAB were taken as the standard results and all other results were compared with reference to it.

3.2.1 Comparison of slider displacements

Analytic results versus simulated results: from the analytic plot of slider displacement against crank angle for both experimental and simulated results shown in figure 10 and 12, the following deductions were made:

- (i) Analytic stroke length = 140 mm; simulated stroke length = 139.71 mm

$$\text{error} = 140 - 139.71 = 0.29 \text{ mm}$$

$$\% \text{error} = \frac{0.29}{140} * 100\% = 0.21\%$$

This value of percentage error is very small, hence, it was neglected. This error was similar to that obtained by, (Babu, 2015).

- (ii) Maximum displacement of slider from analytic plot = 340 mm.

Maximum displacement of the slider from the simulated plot = 250 mm.

$$error = 340 - 250 = 90 \text{ mm}$$

$$\%error = \frac{90}{340} * 100\% = 26.4\%$$

This error was obtained as a result of the differences in the reference coordinate system used in obtaining the analytical results and the simulated results. The error was found to be systematic in nature, hence it was easily corrected by adding 90 mm to the individual slider displacements obtained by simulation using *SolidWorks*. As a result of the systematic nature of the error, the overall result was not majorly affected.

Analytic results versus experimental results: from the analytic plot of slider displacement against crank angle in figure 14

Analytic stroke length = 140 mm; simulated stroke length = 130 mm

$$error = 140 - 130 = 10 \text{ mm}$$

$$\%error = \frac{10}{140} * 100\% = 7.1\%$$

This error was obtained during the fabrication process and the instrumentation process.

- (i) Minimum slider displacement from analytic results = 200mm.

Minimum slider displacement from experimental result = 210 mm.

$$error = 200 - 210 = -10 \text{ mm}$$

$$\%error = \frac{10}{200} * 100\% = 5\%$$

The error above was obtained during measurements.

3.2.2 Comparison of Slider Velocity results

From the analytic plot of slider velocity against crank angle obtained from MATLAB 2014 in figure 11 and the velocity-time graph simulated from SolidWorks in figure 13, it was observed that:

$$V_{\max} \text{ analytical} = 900 \text{ mm/s}$$

$$V_{\max} \text{ simulated} = 840 \text{ mm/s}$$

$$error = 900 - 840 = 60 \text{ mms}^{-1}$$

$$\% error = \frac{60}{900} * 100\% = 6.7\%$$

The error in velocity was obtained because frictional forces was considered during the process of simulation using SolidWorks, these forces were neglected during the process of obtaining the analytical results. *Babu, (2015)* Obtained a similar deduction while comparing the results obtained analytically using MATLAB with that obtained using CATIA, it was noticed that both processes obtained similar results with minor deviations. Similarly, *Frank, (2013)* also verified the use of SolidWorks with a computer program and then deduced that SolidWorks gave minimal error in the kinematic analysis of the mechanism produced.

4. CONCLUSION

The prototype was successfully constructed and compared to both the analytic design and the simulated model. When compared to the analytic design of the Slider-crank mechanism, the SolidWorks model was observed to be fairly accurate with a small percentage error which was justifiably neglected. The model also provided a better understanding of the prototype to be built compared to the analytic design because it gave a visual representation of the design. The prototype that was constructed also showed minor deviations from the theoretical design however, this deviations were largely errors procured

during instrumentation, as a result of the negligible nature of the errors, the prototype can be used for demonstration.

ACKNOWLEDGEMENT

The authors acknowledge the facilities support at Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife and Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta, Ogun State.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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