Experimental Evaluation of Locally Produced Slider-Crank Mechanism Apparatus for Teaching Aids

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Abstract

This work presents a performance evaluation of a designed and constructed slider-crank mechanism apparatus, using locally available materials for teaching aids. This work aims to investigate the possibility of producing cheaper alternative testing apparatus for quality control laboratories and institutions in Nigeria. The Slider-crank mechanism apparatus was built with indigenous materials tested and thereafter compared the results using similar procedures with standard imported slider-crank mechanism device.

The t-Test shows that the constructed apparatus and standard imported slider-crank mechanism apparatus experiment has the t-Stat value, lesser than the critical value (1.690923455) for one tail and 2.032243174 for two tail examination. Hence there is no significant difference difference between the two devices results at 95% confidence. The production cost of the locally fabricated device is ₦16,400.00k and the cost of conventional imported device is $750.00. Therefore the locally produced slider-crank mechanism device is cheaper and can be used as a substitute for the imported equipment in tertiary institutions in Nigeria laboratories

Keywords: Slider-crank, mechanism, performance evaluation, Statistical Analysis - t-test.

1.0 Introduction

The slider crank mechanism is found in every internal combustion engine, piston rod, and crankshaft. The slider crank mechanism is one of the most global tools in the world, with perhaps a billion of it in existence. The slider-crank mechanism is one of the most frequently applied planar linkages in engineering (Kearney et al., 2005, Koser ,2004, Slider-crank mechanism, 2012) According to Ng, the slider-crank system is found in pumps, compressors, steam engines, feeders, crushers, punches, and injectors (Ng, 2003). Furthermore, the slider-crank mechanism is central to diesel and gasoline internal combustion engines, which play an indispensable role in modern living.' The Basic Slider-Crank mechanism is constituted by a rotating element called *Crank* that is connected with a *Slider* by a rigid stick, Connecting Rod (Fung, 1996).

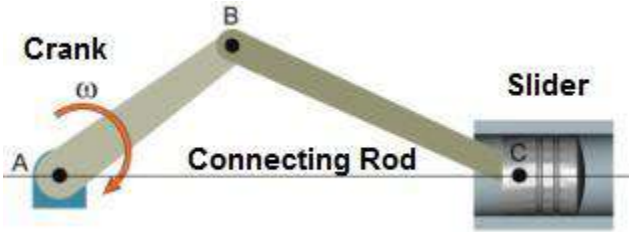

Figure 1.0: Diagram of a typical slider-crank mechanism (Fung, 1996).

When the rotating element is moved, the movement is transmitted to the connecting rod by a rotation joint. This element obligates the slider movement by other rotation joint, generating forward and backward changes in it. It is a reversible system whereby if turned the crank can move the connecting rod, and vice versa. If the connecting rod produces the input motion, the crank is forced to rotate (Fung, 1996).

According to Viscomi *et al*, the response of slider crank is dependent on length, mass, damping, external piston force and frequency (Viscomi and Arye, 1971). Based on the viewpoints of the ratios, distance, and speeds of the crank to the connecting rod, the transient responses have been investigated (Fung, 1996). The slider-crank mechanism apparatus in the laboratory is imported, with high cost and lengthy delivery time, thereby making it difficult to acquire more than one device for a broad set of students offering Mechanics of Machines and other related courses. Due to limited time and monetary resources, engineers need to look inward for the locally produced slider-crank mechanism apparatus with local content of the production. It has been reported, that for technological advancement to flourish in Nigeria, enhancement, and manufacture of the most needed equipment and machines must be based on native designs (Charles-Owaba, 2009, Ismaila, 2008, Akintayo,2009). These will ensure conservation of foreign exchange earnings, maintainability, and affordability to average Nigerians.

2.0 Theory of Slider-Crank Mechanism

The slider-crank mechanism is one of the most frequently applied planar linkages in engineering practice. It is a particular configuration of the four-bar linkage with a slider replacing an infinitely long output link. The most popular application of this mechanism is in the internal combustion engine, wherein the input force is the gas pressure on the piston. The same device is widely used in agricultural and food-processing machines as well as in packing machines. In all these machines, but especially in agrarian tools, the occurrence of variable resistance of relatively high values creates a significant problem. It causes considerable fluctuation in the motion of the whole system. The coefficient of speed fluctuation is one measure of such change (Uziak and Foster, 2001).

This slider-crank mechanism apparatus is meant for measuring angular and linear variations with different linkage position, but according to Norton, measurements can be done only on a real machine after its manufacture, so it is undoubtedly a significant advantage to be able to calculate on a typical prototype of a mechanism (Norton, 1999). The equation of motion of the arrangement must be solved. It is a typical dynamics problem in the category of "forward dynamics" problems (Norton, 1999).

According to Ng, 'there is a difference between a machine and a mechanism. Every kind of machine can transform energy to do work, but only some mechanisms are capable of performing work. The slider-crank mechanism is considered one of the most used systems in the mechanical field (Ng, 2003).

One of the most essential and universal mechanisms is the slider-crank. It was found in pumps, compressors, steam engines, feeders, crushers, punches, and injectors. Furthermore, the slider-crank mechanism is central to diesel and gasoline internal combustion engines, which play an indispensable role in modern living

2.1 Equations of Motion of Slider-Crank Mechanism

The equations of motion of a slider-crank mechanism may be formulated in various ways. Here, we will express the equations of motion for the system shown at the right and impose the necessary constraints to form the slider-crank mechanism. The system as shown in Fig.1.0 consists of two links and an end mass. The system is operated by a torque *T* on the shaft at *A*. It is assumed that the end mass m_3 translates but does not rotate (Fung, 1996).

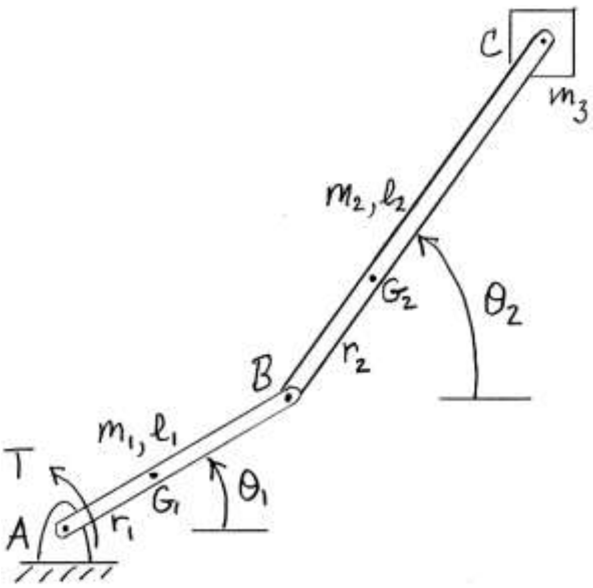

Fig. 2.0: **Motion of a Slider-Crank Mechanism**

Constraint

To convert the system shown in Fig 2.0 into a simple slider-crank mechanism, it requires that;

$$\ell_1 \sin(\theta_1) + \ell_2 \sin(\theta_2) = 0 \qquad (1)$$

This constraint may be put into standard form by differentiating concerning time to get:

$$(\ell_1 \cos(\theta_1))\theta_1 + (\ell_2 \cos(\theta_2))\theta_2 = 0 \qquad (2)$$

Equations of Motion

Using Lagrange's equations with multipliers, the equations of motion of the slider-crank the mechanism may be written in the form

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \theta_i}\right) - \frac{\partial L}{\partial \theta_i} = F\theta_i + \lambda_1 a_{1i} \qquad (i = 1,2) \qquad (3)$$

where (by comparing equation (1.2) with the standard form)

$$a_{11} = \ell_1 \cos(\theta_1) \ \& \ a_{12} = \ell_2 \cos(\theta_2) \qquad (4)$$

Including the kinetic energies of the three bodies and the potential energies associated with the weight forces, it can be shown that

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \theta_1}\right) - \frac{\partial L}{\partial \theta_1} = \left(m_1 r_i^2 + I_1 + m_2 \ell_1^2 + m_3 \ell_1^2\right)\ddot{\theta}_1 + \left(m_2 \ell_1 r_2 + m_3 \ell_1 \ell_2\right)\cos(\theta_2 - \theta_1)\ddot{\theta}_2$$
$$- \left(m_2 \ell_1 r_2 + m_3 \ell_1 \ell_2\right)\sin(\theta_2 - \theta_1)\dot{\theta}_2^2 + \left(m_1 r_1 + m_2 \ell_1 + m_3 \ell_1\right) g \cos(\theta_1) \qquad (5)$$

And

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \theta_2}\right) - \frac{\partial L}{\partial \theta_2} = \left(m_2 r_2^2 + I_2 + m_3 \ell_2^2\right)\ddot{\theta}_2 + \left(m_2 \ell_1 r_2 + m_3 \ell_1 \ell_2\right)\cos(\theta_2 - \theta_1)\ddot{\theta}_1$$
$$+ \left(m_2 \ell_1 r_2 + m_3 \ell_1 \ell_2\right)\sin(\theta_2 - \theta_1)\dot{\theta}_1^2 + \left(m_2 r_2 + m_3 \ell_2\right) g \cos(\theta_2) \qquad (6)$$

The contributions of the driving torque to the equations of motion are,

$$F_{\theta_1} = Tk.\partial\omega_1 / \partial\dot{\theta}_1 = T_{1i} \quad \text{and} \quad F_{\theta_2} = Tk.\partial\omega_2 / \partial\dot{\theta}_2 = 0 \qquad (6)$$

2.3 Applications of the Slider-Crank Mechanism

The slider crank mechanism finds extensive use in reciprocating compressors, piston engines, presses, toggle devices, and other machines where force characteristics are essential. The slider-crank mechanism is such a versatile mechanism of different application. It can be found in household electronics like an electric toothbrush, the compressor of the refrigerator, etc. In outdoor considerations; the slider-crank mechanism can be found in lawn-mowers, cars, and trucks, etc. In industrial application, the slider-crank mechanism can be found in industrial compressors, boilers, turbines, turbochargers, etc. Just put the use of slider-crank mechanism cuts across every sphere and level of human existence [11].

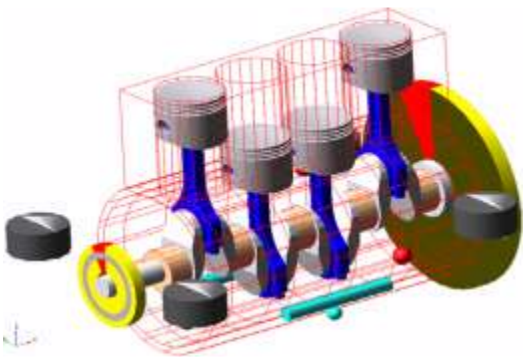

Figure 2.2: Application of a 4-cylinder slider-crank mechanism system (Kearney et al., 2005)

3.0 MATERIALS AND METHOD

3.1 Preliminary Design Considerations

The following factors were considered in the construction of the machine would be carried out; Portability, Cost of production, Availability of materials, Reliability, Durability, Ease of operation, Anthropometry and Ergonomics

3.3 Materials Selection

Most of the material to be used would be sourced within the locality, Ogbomoso to be precise to ensure the reduction of the overall cost of production, thereby achieving one of the cardinal objectives of this project.

1. **Mild Steel**: Mild steel is a very ready and familiar material in our local environment. It is relatively cheap and easily affordable when compared with cast iron. Mild steel was used for the base of the apparatu***s*** because of its high strength, hardness, malleability, machinability, and toughness. Mild steel was also used for the piston guide.

2. **Aluminum**: Aluminium is a light metal which finds application in engine systems where light-weight is needed. The crankshaft, angular scale, connecting rod, and piston was all made from aluminum. Aluminum is preferred because of its lightweight, availability and also because it is cheap and readily available in the local market. The parts stated here would experience relative motion one against another; this brings another characteristic of aluminum to fore, that is its resistance to wear and tear thereby reducing the need for lubrication.

3.4 Cost Consideration

The financial overhead of this project is about ₦16,400.00k It is evident that the locally fabricated apparatus, cost much less than the imported ones because a Scotch Yoke Mechanism working Model Kit, Engineering Mechanism - classroom teaching aid for modeling - mini mechanical project - engineering lab equipment cost 1800 pound sterling and others $750.

3.5 Significance of the Slider-Crank Mechanism Experiment

The purpose of the slider-crank mechanism is to convert the linear motion of the piston to rotational movement of the crankshaft. One typical application of this mechanism is internal combustion engines. The significance of this experiment is that it affords the opportunity of investigating and comparing the possible kinematic relationship between the displacement of the piston and the angle of the crankshaft with that measured for a single-cylinder engine (Kearney et al., 2005). The experiment also gives us insight into the motion profile of a typical slider-crank mechanism. Hence, we can predict the pattern of an arrangement from characteristics data.

3.6 Description of the Apparatus

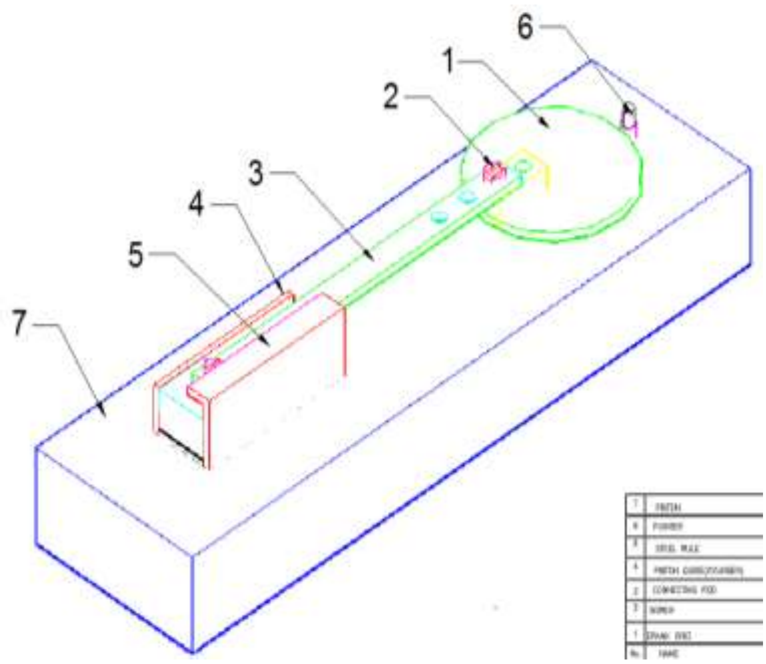

Figure 3.7: Diagram of the Fabricated Apparatus

The slider-crank mechanism apparatus consists of:

1. **The Crank disc**: The crank disc is made of aluminum plate, and it is standardized in degrees vary between 0 and 360 in 5^0 intervals.
2. **Screw**: The screws are made of hardened steel to withstand thread wear.
3. **Connecting Rod**: This is made from an aluminum material (flat bar). It combines the crank disc with the piston.
4. **Piston guide**: This is made from mild steel. It is purposely selected to withstand the vibration of the disk during motion.
5. **Steel rule**: This is made from stainless steel. It is calibrated in millimeters, used to measure linear displacement.
6. **Pointer**: Aluminium material was used to fabricate the tip. It shows the datum of the crank angular readings.
7. **Base**: The base is made from mild steel. It serves as a rigid support for the entire apparatus.

Table 3.1: Component Parts and Functions

S/N	COMPONENT PARTS	FUNCTIONS
1	Crank disc	For measuring angular displacement of the crank. It also provides rotational motion.
2.	Screw	For screwing the crank to the rotating crank disc at different crank radii.
3.	Connecting Rod	Change rotational motion of the crank to linear displacement of the piston.
4.	Piston guide	Serves as an enclosure for the piston and provides linear movement of the cylinder.
5.	Steel Rule	For measuring linear displacement of the piston.
6.	Pointer	Serves as a reference point for measuring angular displacement of the crank.
7.	Base	It provides rigid support for the crank disc, piston guide, and connecting rod.

3.7 Experiment Procedure

The Crank and Connecting-Rod Experiment was set-up using the fabricated apparatus and the conventional imported apparatus as a control to determine the relationship between the crank angle and the stroke; to study the effect of changing the crank radius and the connecting rod length. This work presents the performance evaluation of locally produced friction belt apparatus for laboratory teaching aids and industrial application using indigenous materials in the Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso

Experimental Rig Set-up Procedure:

i. Set up the apparatus as previously described in section 3.6 so that both crank radius and connecting rod lengths are at a maximum.
ii. With the crank arm at Bottom Dead Centre (BDC) set the piston mark to zero on the scale by adjusting the position of the guide block.
iii. Rotate the crank through 10^o and read off as accurately as possible the new position of the pointer.
iv. Continue in 10^o steps through 180^o until the crank is at Top Dead Centre (TDC).
v. The results were recorded and presented in Figures 4.1 - 4.10 for different varying parameters for both the fabricated apparatus and the standard imported apparatus: Figure 3.0: shows a perspective view of the fabricated device from the rear
vi. Graphical comparison of the results obtained between the standard and fabricated equipment as presented in Figures 4.6 - 4.10 and statistical comparison of the results obtained between the standard and fabricated device using a t-test for both one tail and two-tail test assuming unequal variance as presented in Table 1-0

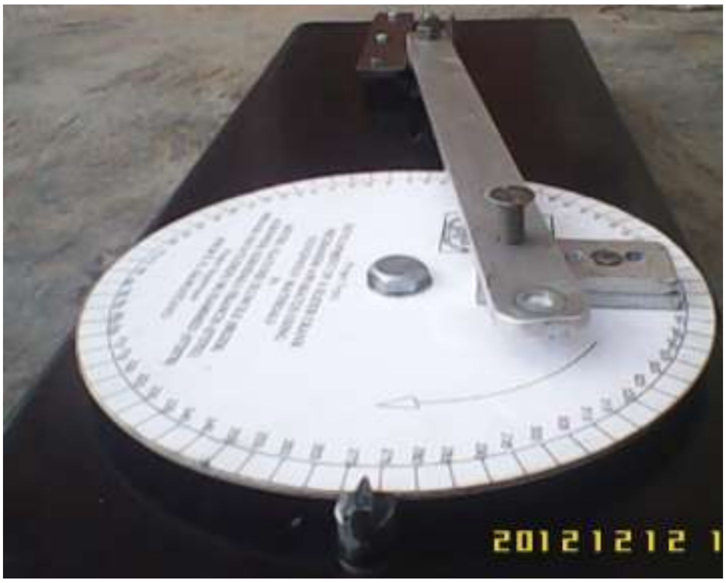

Figure 3.0: Showing a perspective view of the fabricated apparatus from the rear

4.0 Results and Discussion

The results recorded from the experimental set-up and its interpretations and discussions as presented follow:

4.1 Graphical Results of Standard Apparatus

From fig. 4.1, it can be seen that the maximum displacement is 51mm at a range of 37.5mm. From Fig. 4.2 it can also be observed that the maximum movement is 50.5 at 25mm crank angle, 225mm connecting rod length.

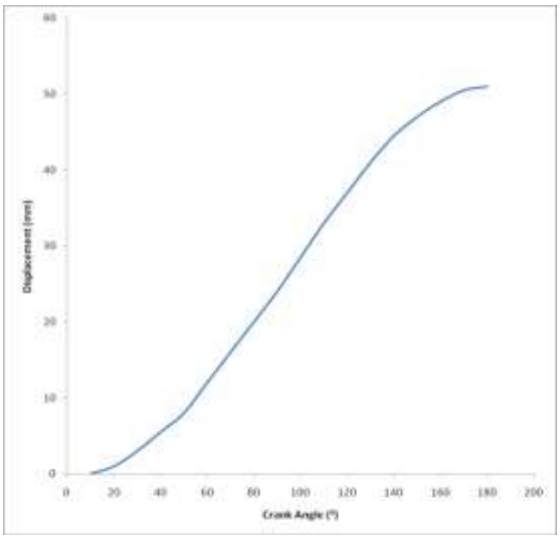

Fig. 4.1: Graph of Displacement against Crank angle at 37.5mm imported apparatus (standard)

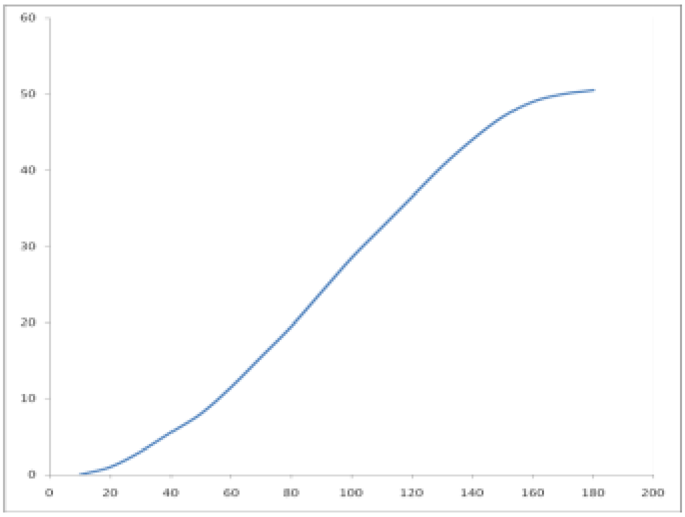

Fig. 4. 2: Graph of Displacement Against Crank angle at the 25mm radius at 225mm Connecting Rod Length for imported apparatus (standard)

4.2 Graphical Results of Fabricated Apparatus

Fig. 4.3 shows the graph of displacement Graph of Displacement against crank angle (75mm radius) at 300mm Connecting Rod Length for fabricated apparatus; the maximum displacement is 144mm. Fig. 4.4 Graph of Displacement against Crank Angle of Fabricated Apparatus (75mm radius) at 265mm connecting rod length, the maximum movement is 146mm. It can be deduced that at the same limit, irrespective of the connecting rod length, the piston displacement is approximately the same.

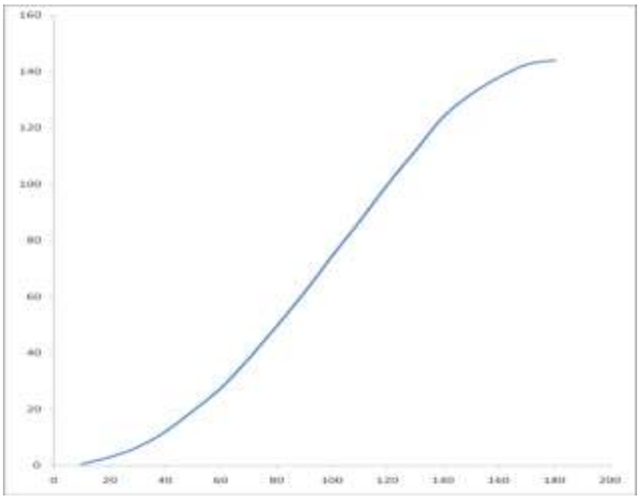

Fig. 4. 3: Graph of Displacement against crank angle (75mm radius) at 300mm Connecting Rod Length for fabricated apparatus

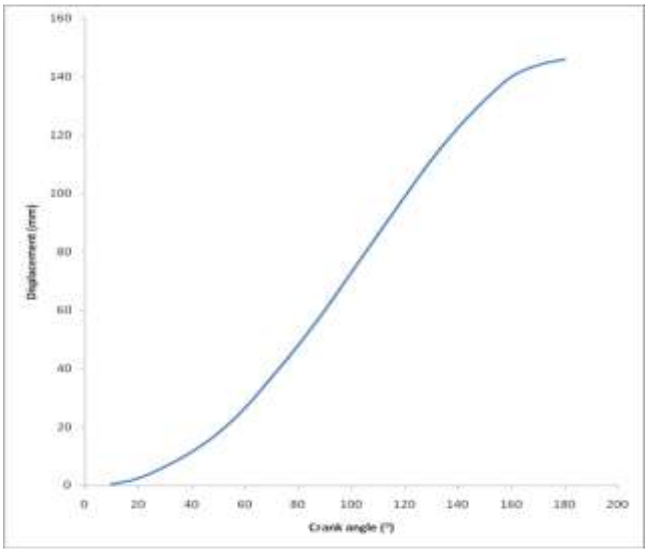

Fig. 4.4: Graph of Displacement against Crank Angle of Fabricated Apparatus (75mm radius) at 265mm connecting rod length

4.3 Comparison of Standard Apparatus with Fabricated Apparatus

Fig. 4.5 shows the result of conventional apparatus and fabricated apparatus at maximum connecting rod length; it can be seen that both curves have the same trend/pattern, though the curve for the fabricated device exceeds 100mm displacement (precisely 109mm) while the standard apparatus curve is just on the 100mm displacement mark. It may be because the newly fabricated apparatus possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher displacement observed.

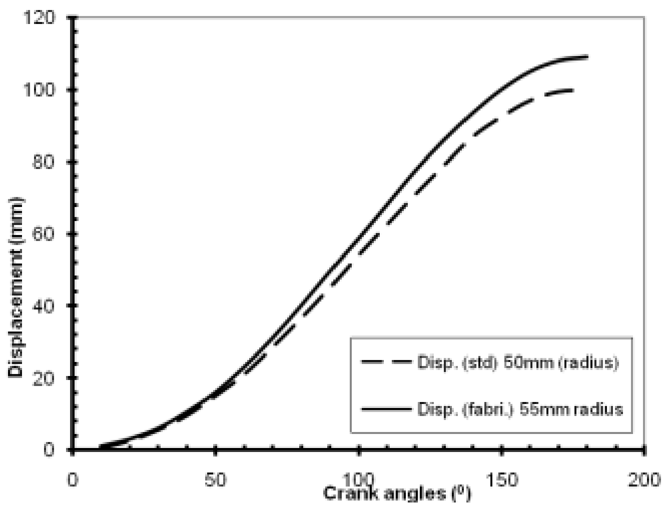

Fig. 4.5: Graphical Comparison of Standard Apparatus and Fabricated Apparatus for Maximum Connecting Rod Length (300mm for fabricated, 250mm for standard)

Fig. 4.6 shows the results of conventional apparatus and fabricated apparatus at medium connecting rod length. It is deduced that both curves have the same trend/pattern, though the curve for the fabricated device exceeds 100mm displacement (precisely 108.5mm) while the standard apparatus curve is just on the 100mm displacement mark. It may be because the newly fabricated apparatus possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher displacement observed.

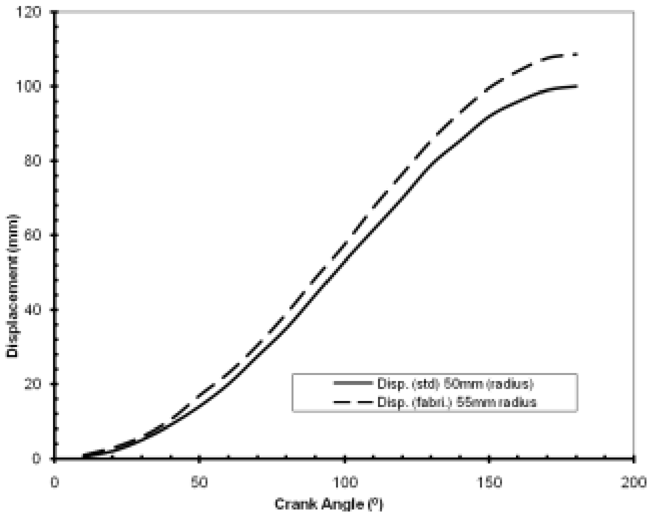

Fig. 4. 6: Graphical Comparison of Standard Apparatus and Fabricated Apparatus at Medium Connecting Rod Length

Fig. 4.7 shows the result of conventional apparatus against fabricated apparatus at minimum connecting rod length. It can be seen that both curves have the same trend/pattern. While the curve for the fabricated device exceeds 100mm displacement (precisely 108) the standard apparatus curve is just on the 100mm displacement mark. It may be because the newly fabricated apparatus possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher displacement observed.

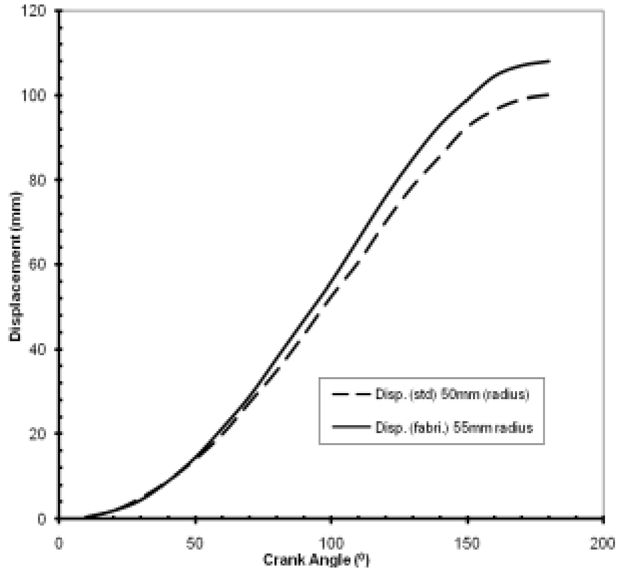

Fig. 4.7: Graphical Comparison of Standard Apparatus and Fabricated Apparatus at Minimum Connecting Rod Length

Fig. 4.8 shows a conventional apparatus against fabricated apparatus at the maximum connecting rod length. It can be seen that both curves have the same trend/pattern. While the curve for the standard device exceeds 70mm displacement (precisely 76) the fabricated apparatus curve is just on the 70mm displacement mark This may be because the newly fabricated device possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher the displacement observed.

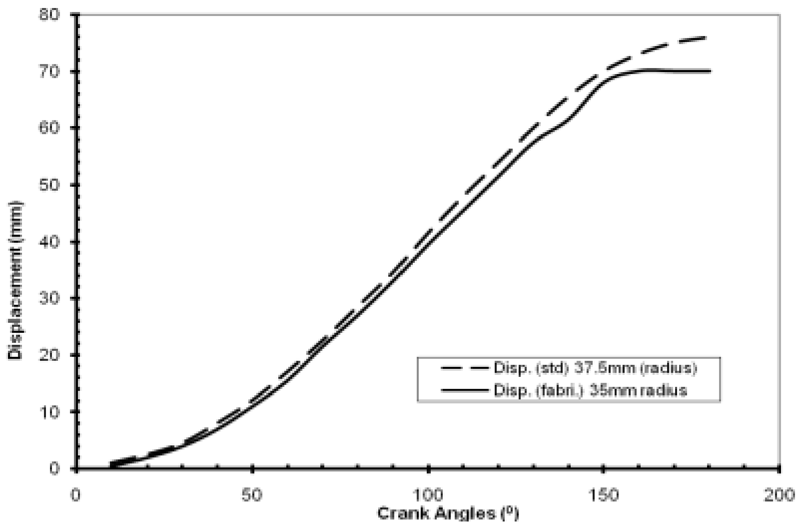

Fig. 4.8: Graphical Comparison of Standard Apparatus and Fabricated Apparatus at Maximum Connecting Rod Length

Fig 4.9 shows the standard result apparatus and fabricated apparatus at medium connecting rod length. It can be seen that both curves have the same trend/pattern. While the curve for the standard device has its maximum displacement at 75mm, the fabricated apparatus curve has its highest at the

70mm displacement mark. It may be because the newly fabricated device possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher displacement observed.

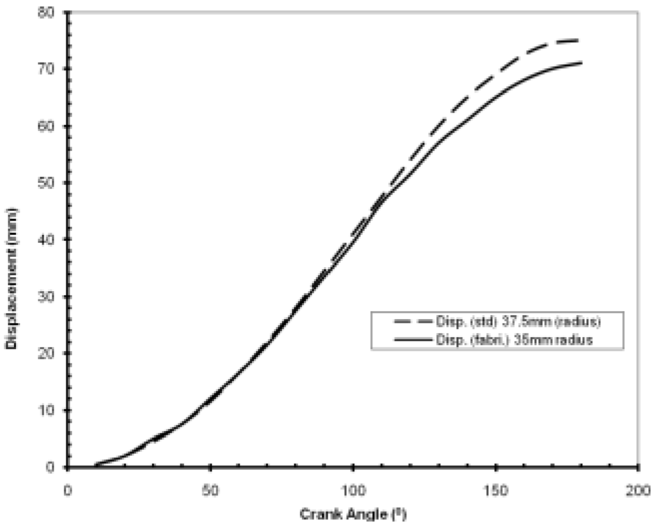

Fig. 4.9: Graphical Comparison of Standard Apparatus and Fabricated Apparatus at Medium Connecting Rod Length

Fig. 4.10 shows the results of conventional apparatus and fabricated apparatus at medium connecting rod length. It is evident that both curves have the same trend/pattern. While the curve for the standard apparatus has its maximum displacement at 75mm, the fabricated apparatus curve has its highest at the 70mm displacement mark This may be due to the fact that the newly fabricated apparatus possesses surface imperfection that would be taken care of by first wear, yet the characteristic profile looks alike. It shows that connecting rod length has no effect on the performance and characteristics of a slider-crank mechanism, and at the same, while radius does not alter the motion profile, the bigger space, the higher displacement observed. Summary of a t-test: two-samples assuming unequal variances for the standard apparatus and fabricated apparatus results as presented in Table 1.0 and Bill of Engineering Materials and Evaluation (BEME) for Slider-crank Mechanism Apparatus as shown in Table 2.0.

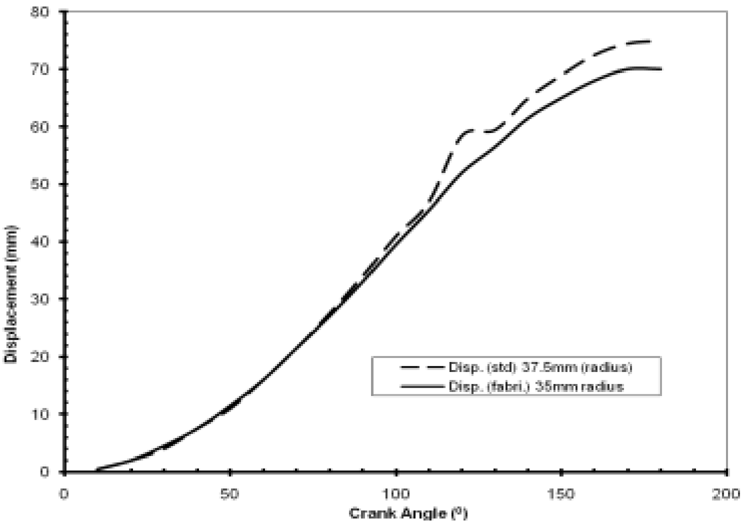

Fig. 4.10: Graphical Comparison of Standard Apparatus and Fabricated Apparatus at Minimum Connecting Rod Length

Table 1.0: Summary of a t-test: two-samples assuming unequal variances for the standard apparatus and fabricated apparatus results

S/n	Experiments	t-stat	t-critical one tail	t-critical two tail
1.	Maximum connecting rod length, (radius; 50-55mm)	-0.34470538	1.690923455	2.032243174
2.	Medium connecting rod length, (radius; 50-55mm)	0.372402273	1.690923455	2.032243174
3.	Minimum connecting rod length, (radius; 50-55mm)	0.300246411	1.690923455	2.032243174
4.	Maximum connecting rod length, (radius; 35-37.5mm)	0.239782325	1.690923455	2.032243174
5.	Medium connecting rod length, (radius; 35-37.5mm)	0.188925686	1.690923455	2.032243174
6.	Minimum connecting rod length, (radius; 35-37.5mm)	0.216060776	1.690923455	2.032243174

Table 1.0 shows the statistical comparison between the standard and fabricated apparatus using both one tail and two-tail test assuming unequal variance. The number of observed readings is 18 for both devices. The t-Critical is greater than the t-Stat, i.e., t-Stat < t-Critical for both one-tail and two tail test, it can be concluded that there is no significant difference between the standard apparatus and the fabricated apparatus at 95% confidence limit for all the six different experiments conducted shown in Figure 4.5 – 4.10. Hence the fabricated slider crack mechanism apparatus with locally sourced materials produced the same experimental results, with standard costly imported of the same equipment which some Nigerians cannot afford to purchase when comparing cost and shipping prices as

Table 2.0. Bill of Engineering Materials and Evaluation (BEME) for Slider-crank Mechanism Apparatus

S/n	Material	Quantity	Price (₦)	Total (₦)
1.	3 mm Aluminium plate	1	5,000.00	
2.	1 inch flat bar	1	1,500.00	
3.	Aluminium plate	1	2,500.00	
4.	Screws, bolts, nuts, washer, try square		3,000.00	
5.	Material cost			12,000.00
6.	Overhead		1200	
7.	Contingence		1440	
8.	Miscellaneous		1800	
				4440
	Total cost			16,440.00

5.0 Conclusions

The crank radius was varied with the different connecting rod length; it is observed that the characteristic graphs are similar. Hence, it is concluded that size does not alter the effectiveness of a slider-crank mechanism.

Also, a critical comparison of the graph of the experiments carried out on the imported apparatus looks alike with that carried out with the locally fabricated one. Thus, it can be concluded that the locally built device can be used instead of the imported one to save the cost of importation. It has been established that the results of the relationship between the displacement of piston and change in crank angle when using standard apparatus and fabricated apparatus with indigenous material have no significant difference at 95% confidence limit, for all the experiments carried out on the device. Hence, the fabricated device is reliable. The economic feasibility of the fabricated apparatus with available indigenous materials is better compared to the exorbitant cost of the conventional device which many Nigerian institutions cannot afford. The fabricated device with native elements is affordable to an average Nigerian institution at a production cost of ₦16,440.00k, as against the sum of $750.00 for the purchase of the conventional imported device.

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