APPLICATION OF VIRTUAL MECHANISM IN ENGINEERING LABORATORY EXPERIMENT

Case Study: Slider Crank Mechanism

By

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1.0 ABSTRACT

Application of virtual mechanisms in performing laboratory experiments is a concept which will make laboratory mechanisms available to students in the right quantity through computer. The concept will allow students to perform laboratory experiments within and outside their institutions without restriction to laboratory. Slider crank mechanism was used as a case study because it is a fundamental mechanism in mechanical systems in many industrial machines and automobiles. Students are made to perform experiments on this mechanism in order to understand its characteristics. This paper highlights how problems that are associated with practical works among students can be solved using virtual mechanisms. It went further to give theoretical analyses of slider crank mechanism. The formulas generated from the analyses were used for computer simulation using Microsoft Visual Basic 6.0. Experiments were performed with virtual (Computer Simulated) and real mechanisms separately using the same procedure in a typical laboratory experiment. The results of the experiments conducted were compared to justify its acceptability.

Key words: *Virtual, mechanism, simulated, laboratory*

2.0 INTRODUCTION

Engineering laboratories have long been a valued element within the higher education curriculum, providing an effective learning vehicle that is popular with students.

Unfortunately they can be expensive for academics to operate and assess, and time-consuming for the students who undertake them [11]. Laboratory work is the hallmark of education in science and technology based fields. In the laboratory, students can explore their understanding of the subjects being taught by placing their learning in context. Students can also be motivated to learn in the laboratory context if they can feel excited when investigating a scientific phenomenon, or when creating something that actually works [3].

Laboratory practical work in mechanics of machine is very important in mechanical engineering because this is where basic fundamental principles of machine design are learnt. In view of this, every effort must be geared towards giving students sound education in mechanics of machines laboratory work. It is a known fact that many higher institutions of learning in third world countries have limited number of slider crank and other mechanisms in their laboratories. Students are always grouped together to carry out experiments in most cases, the grouped members are large to the extent that some students do not participate in carrying out the experiments because of lack of equipment. Students always find it difficult to have better understanding of the mechanisms they use in their practical works because the time they have to interact with only available one is limited.

Computer simulated slider crank mechanism will allow the students to carry out the following:

- perform their experiment individually
- study the mechanism with different dimensions of variables
- get accurate results devoid of errors from linkage misalignment
- generate report at faster rate using Microsoft office.

One obvious advantage of this concept is that students can be given different data inputs during the experiments in order to ascertain participation of individual students.

3.0 Present and past development in virtual prototyping

Researchers all over the world are carrying out research works in related fields to this research project. In Department of Chemical Engineering, King Fahd University of Petroleum & Minerals, Dhahran-31261, Kingdom of Saudi Arabia virtual laboratory was developed for fluid mechanics practical.

The laboratory consists of four experiments dealing with losses in piping systems, flow meters, packed and fluidized beds. The laboratories can be run on any PC running a 32-bit operating system and could be made available through Internet. With the ability to vary different parameters in the experiments, students can develop an intuitive sense of cause-and-effect.

The benefit of the research work was stated as follows **[12]**: "The installation, running and maintenance cost of chemical engineering teaching laboratory are usually high. Once a real experiment is installed, it is difficult to modify it. It limits the students to performing experiments within a narrow range of parameters. In addition, experiment running time is too long to repeat a run or to vary parameters in a bigger range. A simulated mechanism for laboratory work removes these difficulties by allowing students to perform virtual experiments effortlessly on a microcomputer. In fact, one can create situations, which are impossible in real life but are pedagogically important.

Once a virtual laboratory is installed on a website, more students can benefit. Students can perform experiments from any location and at any time. The ease of running allows them to repeat an experiment with varying parameters, exploring what would happen under different scenarios. Readily available multimedia based help enhances the basic understanding of the subject. The students can learn the basic concepts without getting lost into performing details of a real experiment. **[6]**

Some prototype virtual laboratories are already opened to users in the following institutions through internet

- University of Oregon physics virtual laboratory
- National University of Singapore, Electrical Engineering Department, virtual laboratory for oscilloscope experiments [7]
- The Centre for Water Research, Department of Environmental Engineering at the University of Western Australia virtual lab for Fluid Mechanics **[8]**, where students conduct experiments and write their reports online.

By permitting designers to realistically, accurately and quantitatively prototype and test multiple intermediate models within virtual environment, Virtual Prototyping (VP), also known as Simulation-Based

Design (SBD),has rapidly gained popularity and become a crucial part of most engineering design processes. While there is a significant demand from industry for students trained in this methodology, currently there is not much room in engineering curriculum to permit widespread adoption in the lecture-based classroom. [13]

Virtual Laboratory development also includes automatic reporting of laboratory work using specially developed instruction sheet from Microsoft Word documents and their companion Visual Basic for Applications development environment.

Positive observations from this development include improved assessment efficiency for staff and a productive learning experience for students. [11]

4.0. Theory of Slider Crank Mechanism

A special form of four bar link mechanism is called slider crank mechanism. The relative motion of the follower with the ground link is translational. Many engineering system designs are based on slider crank mechanism. The most prominent among them are automobile engines, compressors and pumps.

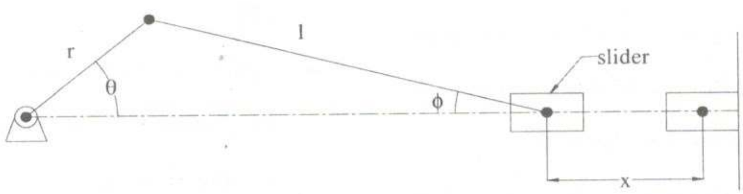


Fig 1.0 slider crank mechanism

If the crank shaft of radius r in fig 1.0 above rotates at constant angular velocity, the slider motion is nearly sinusoidal. Deviation from a true sine wave is caused by the swinging of the connecting rod. For a given crank radius, the longer the connecting rod, the more nearly is the motion sinusoidal [1].

The axis of the slider passes through the axis of rotation of the crank shaft of radius r. Displacement equation x of the slider from its right-hand extreme (dead-centre) position is,

$$x = (r + l) - (r\cos\theta + l\cos\phi) \qquad (1)$$

and $\cos\phi = \sqrt{\left[1 - \left(\frac{\sin\theta}{n}\right)^2\right]}$

where $n = \frac{l}{r}$

The slider displacement, velocity, and acceleration equations are shown below (2, 3, 4 and 5 respectively)

Slider displacement equation [5]

$$x = r(1 - \cos\theta) + l\left[1 - \sqrt{\left[1 - \left(\frac{\sin\theta}{n}\right)^2\right]}\right] \qquad (2)$$

$$x = r\left[1 - \cos\theta + (n) - \sqrt{(n^2 - \sin^2\theta)}\right] \qquad (3)$$

Slider velocity equation [8]

$$v = \frac{d}{dt}x = \omega r\left[\sin\theta + \frac{\sin 2\theta}{2\sqrt{(n^2 - \sin^2\theta)}}\right] \qquad (4)$$

Slider acceleration equation [5]

$$f = \frac{d^2}{dt^2}x = \omega^2 r\left[\cos\theta + \frac{\sin^4\theta + n^2\cos 2\theta}{(n^2 - \sin^2\theta)^{\frac{3}{2}}}\right] \qquad (5)$$

If the terms $\sin^4\theta$ and $\sin^2\theta$ are neglected, the approximate expression for f is

$$f = \omega^2 r\left(\cos\theta + \frac{\cos 2\theta}{n}\right) \qquad (6)$$

5.0 Experiment Method

The parameters of real slider crank mechanism model shown in Fig. 3.0 below were used for the simulation of the virtual model of slider crank mechanism shown in fig 2.0 below. The computer program for the simulation was developed using Microsoft Studio Visual Basic 6.0 by the authors of this paper. It can be made available on special request.

The virtual model mechanisms crank rotates through a mouse driven slider control which indicates angular position of the crank. The parameters of the real mechanism are filled in the text boxes provided for them in order to produce a replica on the real model in Fig 3.0. The crank of the mechanism was initially set to 0^0 as shown in Fig. 2.0. The crank was rotated through 15^0 steps until it has turned through 360^0. At each step, the slider displacement shown on the linear scale from 0cm (top dead centre) was recorded. The same experimental procedure was used for the real model. The data generated from the experiments are shown in Table 1.0. The graphs of displacements of the slider against corresponding crank angles were plotted as shown in fig. 4.0 below.

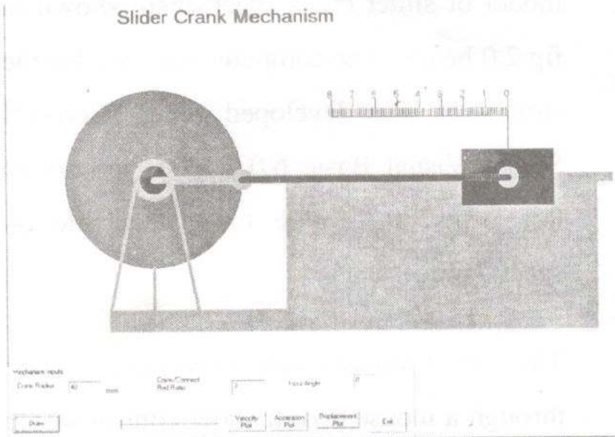


Fig. 2.0 Virtual Model

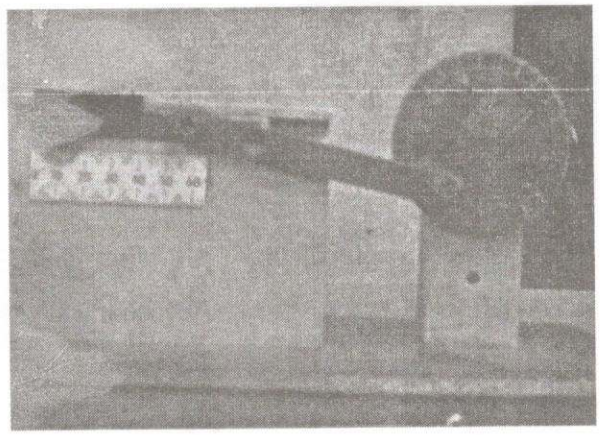


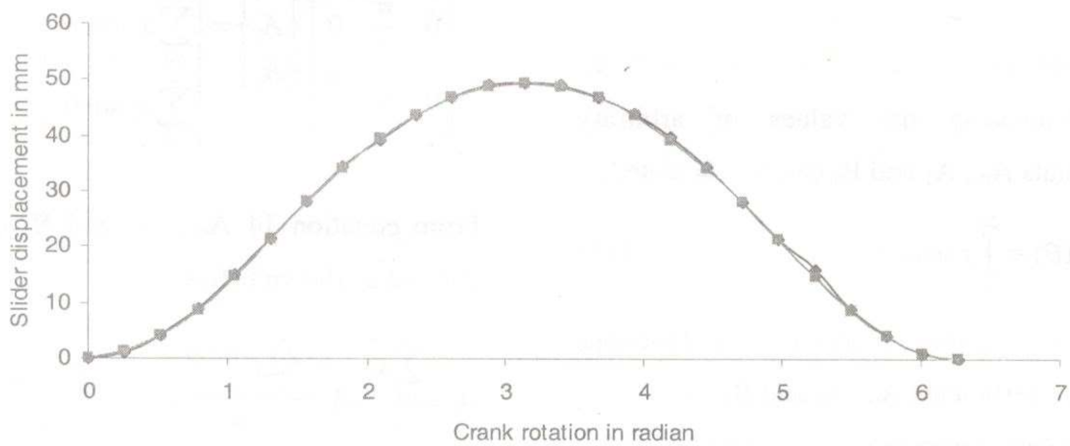
Fig. 3.0 Real Model

Table 1.0: Parameters and Results of Laboratory and Computer Simulated Slider Crank Mechanisms

Readings obtainted from laboratory/simulated slider crank mechanisms

Crank radius in mm	Link ratio	Crank angle in degrees	Crank angle in radians	Slider displ. in mm (lab. scm)	Slider displ. in mm (simu. scm)
24.75	4.08	0	0	0	0
24.75	4.08	15	0.26	1	1.25
24.75	4.08	30	0.52	4	4
24.75	4.08	45	0.79	8.8	8.75
24.75	4.08	60	1.05	15	14.75
24.75	4.08	75	1.31	21.5	21.25
24.75	4.08	90	1.57	28	28
24.75	4.08	105	1.83	34.5	34
24.75	4.08	120	2.09	39.2	39.5
24.75	4.08	135	2.36	43.8	43.75
24.75	4.08	150	2.62	47	47
24.75	4.08	165	2.88	49	48.75
24.75	4.08	180	3.14	49.5	49.5
24.75	4.08	195	3.4	49	48.75
24.75	4.08	210	3.67	47	47
24.75	4.08	225	3.93	44.2	43.75
24.75	4.08	240	4.19	40	39.25
24.75	4.08	255	4.45	34.5	34
24.75	4.08	270	4.71	28.2	28
24.75	4.08	285	4.97	21.5	21.25
24.75	4.08	300	5.24	16	14.75
24.75	4.08	315	5.5	9	8.75
24.75	4.08	330	5.76	4.2	4
24.75	4.08	345	6.02	1	1
24.75	4.08	360	6.28	0	0

Fig 4.0 Graphs obtained from lab. scm and simu. scm



6.0 Experiment results analysis

The velocities and accelerations at each point plotted can be calculated by finding the gradients of the curves in fig.4.0. This is the conventional method that is being adopted in manual computation. In order to computerize the experiment to facilitate e-learning, least square theory in numerical methods is adopted to generate the equations of the curves. The velocities and accelerations at the plotted points are found by differentiating the curves' equations that will be obtained from the analysis explained below. Each of the curves in fig. 4.0 is considered sinusoidal; therefore their equations can be described by equation 7.

$$x = A_0 + A_1 \cos\theta + B_1 \sin\theta + e \qquad (7)$$

$$x_i - e = A_0 + A_1 \cos\theta_i + B_1 \sin\theta_i \qquad (8)$$

$$S_r = \sum_{i=0}^{n} (x_i - A_0 + A_1 \cos\theta_i + B_1 \sin\theta_i)^2 \qquad (9)$$

Where $S_r = x_i - e$

The normal equations to accomplish minimization of equations are generated from the partial derivatives

$$\frac{\partial S_r}{\partial A_0} = 0 \quad \frac{\partial S_r}{\partial A_1} = 0 \quad \text{and} \quad \frac{\partial S_r}{\partial B_1} = 0$$

$$A_0 n + A_1 \sum_{i=0}^{n} \cos\theta_1 + B_1 \sum_{i=0}^{n} \sin\theta_i = \sum_{i=0}^{n} x_i \qquad (10)$$

$$A_0 \sum_{i=0}^{n} \cos\theta_i + A_1 \sum_{i=0}^{n} \cos^2\theta_i + B_1 \sum_{i=0}^{n} \sin\theta_i \cos\theta_i = \sum_{i=0}^{n} x_i \cos\theta_i \qquad (11)$$

$$A_0 \sum_{i=0}^{n} \sin\theta_i + A_1 \sum_{i=0}^{n} \cos\theta_i \sin\theta_i + B_1 \sum_{i=0}^{n} \sin^2\theta_i = \sum_{i=0}^{n} x_i \sin\theta_i \qquad (12)$$

n in equations 10,11 and 12 represents the number of points to be evaluated.

By solving equations 10, 11, and 12 simultaneously the values of arbitrary constants A_0 , A_1 and B_1 can be calculated.

$$\sum_{i=0}^{n} f(\theta) \equiv \int_{0}^{2\pi} f(\theta) d\theta \qquad (13)$$

By using equation 13 above on the functions of the coefficients A_0 , A_1 and B_1

The matrix equation below is derived **[4]**

$$\begin{bmatrix} n & 0 & 0 \\ 0 & \frac{n}{2} & 0 \\ 0 & 0 & \frac{n}{2} \end{bmatrix} \begin{Bmatrix} A_0 \\ A_1 \\ B_1 \end{Bmatrix} = \begin{Bmatrix} \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i \cos\theta_i \\ \sum_{i=1}^{n} x_i \sin\theta_i \end{Bmatrix} \qquad (14)$$

From equation 14 A_0 , A_1 and B_1 can be derived as shown below.

$$A_0 = \frac{\sum_{i=1}^{n} x_i}{n}, A_1 = \frac{2\sum_{i=1}^{n} x_i \cos\theta_i}{n}, B_1 = \frac{2\sum_{i=1}^{n} x_i \sin\theta_i}{n}$$

Table 2.0 below is used for the determination of A_0, A_1 and B_1 values of real model mechanism

x in mm	θ in rad	xcosθ	xsinθ
0	0	0	0
1	0.26	0.96639	0.257081
4	0.52	3.471277	1.987521
8.8	0.79	6.193839	6.251109
15	1.05	7.463566	13.01135
21.5	1.31	5.543776	20.77298
28	1.57	0.022297	27.99999
34.5	1.83	-8.84273	33.34751
39.2	2.09	-19.4506	34.03401
43.8	2.36	-31.0889	30.85319
47	2.62	-40.7503	23.4183
49	2.88	-47.333	12.67235
49.5	3.14	-49.4999	0.078836
49	3.4	-47.3731	-12.5215
47	3.67	-40.5897	-23.6955
44.2	3.93	-31.1599	-31.348
40	4.19	-19.9581	-34.6652
34.5	4.45	-8.9489	-33.3192
28.2	4.71	-0.06737	-28.1999
21.5	4.97	5.477579	-20.7905
16	5.24	8.055531	-13.8242
9	5.5	6.378028	-6.34986
4.2	5.76	3.638175	-2.0985
1	6.02	0.965566	-0.26016
0	6.29	0	0
25.436		-11.8755	-0.09553

$$A_0 = \frac{\sum_{i=1}^{n} x_i}{n} = 25.44 \qquad A_1 = \frac{2\sum_{i=1}^{n} x_i \cos\theta_i}{n} = -23.751,$$

$$B_1 = \frac{2\sum_{i=1}^{n} x_i \sin\theta_i}{n} = -0.19106$$

Equation of the curve generated by real model mechanism is given by

$$x = 25.436 - 23.751\cos\theta - 0.191\sin\theta \quad (15)$$

Velocity equation of the real model mechanism ;

$$\frac{dx}{dt} = \omega(23.751\sin\theta - 0.191\cos\theta) \quad (16)$$

Acceleration equation of the real model mechanism

$$\frac{d^2x}{dt^2} = \omega^2(23.751\cos\theta + 0.191\sin\theta) \quad (17)$$

Table 3.0:for determining A_0, A_1 B_1 values of virtual model mechanism

x in mm	θ in rad	xCosθ	xsinθ
0	0	0	0
1.25	0.26	1.207987	0.321351
4	0.52	3.471277	1.987521
8.75	0.79	6.158647	6.215591
14.75	1.05	7.339173	12.79449
21.25	1.31	5.479313	20.53143
28	1.57	0.022297	27.99999
34	1.83	-8.71457	32.86421
39.5	2.09	-19.5995	34.29448
43.75	2.36	-31.0534	30.81797
47	2.62	-40.7503	23.4183
48.75	2.88	-47.0915	12.60769
49.5	3.14	-49.4999	0.078836
48.75	3.4	-47.1314	-12.4576
47	3.67	-40.5897	-23.6955
43.75	3.93	-30.8427	-31.0289
39.25	4.19	-19.5839	-34.0152
34	4.45	-8.81921	-32.8363
28	4.71	-0.06689	-27.9999
21.25	4.97	5.413887	-20.5488
14.75	5.24	7.426192	-12.7442
8.75	5.5	6.200861	-6.17348
4	5.76	3.464928	-1.99857
1	6.02	0.965566	-0.26016
0	6.29	0	0
25.24		-11.8637	0.006933

Equation of the curve generated by virtual model mechanism is given by

$$x = 25.24 - 23.727\cos\theta - 0.014\sin\theta \quad (18)$$

Velocity equation of the virtual mechanism model

$$\frac{dx}{dt} = \omega(+23.727\sin\theta - 0.014\cos\theta) \quad (19)$$

Acceleration equation virtual model mechanism

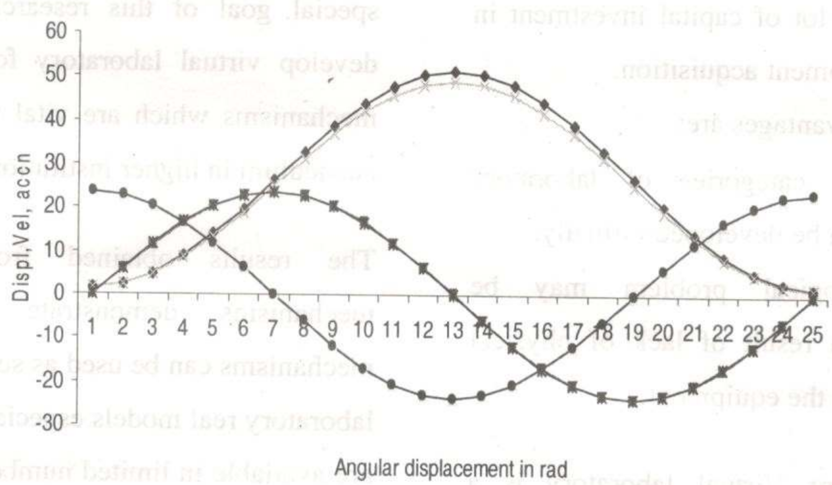
$$\frac{d^2x}{dt^2} = \omega^2(23.727\cos\theta + 0.014\sin\theta) \quad (20)$$

ω is assumed to be 1 rad/s in computation of values in table 4.0

Table 4.0: Displacement, velocity and acceleration of both real model and virtual model mechanisms sliders using equations 15, 16,17,18,19 and 20

θ in rad	x (real)	vel(real)	accn (real)	x (virtual)	vel (virtual	accn (virtual)
0	1.685	-0.191	23.751	1.513	-0.014	23.74091
0.26	2.540096	5.92134	23.00183	2.306866	6.086221	22.93746
0.52	4.930777	11.63565	20.70648	4.642298	11.77733	20.57708
0.79	8.944796	16.73717	16.85271	8.529917	16.8447	16.7066
1.05	14.01661	20.50713	11.98349	13.42199	20.57438	11.81977
1.31	19.92755	22.89861	6.308737	19.10847	22.92106	6.130342
1.57	26.2803	23.75084	0.209913	25.20711	23.72698	0.031659
1.83	32.64781	23.00654	-5.90302	31.30796	22.93797	-6.06829
2.09	38.60207	20.71574	-11.6192	37.00092	20.60707	-11.7621
2.36	43.91939	16.86603	-16.7237	42.07139	16.72349	-16.8421
2.62	47.85059	11.99981	-20.4976	45.80497	11.83439	-20.5812
2.88	50.3466	6.32697	-22.8936	48.15617	6.149785	-22.9187
3.14	51.23965	0.228827	-23.7507	48.96695	0.051789	-23.7154
3.4	50.4697	-5.8847	-23.0112	48.1828	-6.04969	-22.9364
3.67	47.96657	-11.8093	-20.6079	45.73796	-11.9501	-20.5014
3.93	44.08295	-16.7103	-16.8793	41.97689	-16.8181	-16.7256
4.19	39.0174	-20.488	-12.0161	37.09077	-20.5555	-11.8251
4.45	33.11043	-22.8885	-6.3452	31.40803	-22.9113	-6.14062
4.71	26.7591	-23.7505	-0.24774	25.31068	-23.7269	-0.0427
4.97	20.39036	-23.0159	5.866372	19.20858	-22.9476	6.058948
5.24	14.21694	-20.6173	11.79291	13.30625	-20.5075	11.9598
5.5	9.108618	-16.8926	16.69686	8.43527	-16.7503	16.81896
5.76	5.169347	-12.0324	20.47845	4.693907	-11.8671	20.54052
6.02	2.663924	-6.36342	22.88347	2.333653	-6.18627	22.91643
6.29	1.759212	-0.02914	23.75175	1.513456	0.147691	23.7402

Fig 5.0 Graphical display of Real and Virtual Mechanism data in table 4.0



7.0 Experiment Results Discussions: The horizontal axis in fig. 5.0 marks are at 15^0 intervals from each other. The marks indicate the various positions of the mechanisms cranks during the experiments.

The different graphs plotted from the data generated from real and virtual model mechanisms for displacement, velocity and acceleration overlapped. This is an indication that the two mechanisms have the same attribute, thus they can compliment each other. The least square theory in numerical method adopted to generate the function of the displacement curves produced functions which perfectly predicted the displacements, velocities and accelerations at the various positions of the mechanisms except the initial positions.

The graphs clearly showed the relationship that exists between the mechanisms velocity and acceleration at the top dead centre point 13 in fig. 5.0. When the displacement of the slider is 50mm (stroke length), the velocity is 0m/s while the acceleration magnitude is maximum. The main advantages of the virtual mechanism over the real counterpart are:

- It allows parameter changes in order to investigate the outcome of different experimental conditions.
- It can be replicated (as many as possible) for large number of people to work independently.
- It creates avenue for laboratory work to be done at remote locations via internet

- It saves a lot of capital investment in laboratory equipment acquisition.

The main disadvantages are:

- Not all categories of laboratory experiments can be developed virtually.
- Psychological problem may be developed as a result of lack of physical interaction with the equipment.

8.0 Conclusion: Virtual laboratory is a concept which is being developed and integrated into educational system in some countries. Its emergence is as a result of advancement in Information and Communication Technology (ICT). The special goal of this research work is to develop virtual laboratory for engineering mechanisms which are vital to engineering curriculum in higher institutions of learning.

The results obtained from the two mechanisms demonstrate that virtual mechanisms can be used as substitutes to the laboratory real models especially where they are available in limited number. However, it is advisable that real laboratory models should be demonstrated to the students before they are allowed to perform experiment on the virtual mechanism.

9.0 Table of Symbols

r – Mechanism crank radius

l -- Connecting rod length

x – Arbitrary displacement of mechanism slider

θ – Angular displacement of the crank position

ϕ – Angular displacement of the connecting rod

n – Ratio of connecting to the crank radius

v – Slider velocity

ω – Crank angular velocity

f – Slider acceleration

A_0, A_1, B_2 arbitrary constants of sinusoid equation model of fig 4.0 graphs

e -- curve fitting error of sinusoid equation (7)

S_r – sum of residual value square

Vel--Velocity

Accn--Acceleration

Simu. scm—Simulated slider crank mechanism

Lab. Scm – Laboratory slider crank mechanism

Displ. – Displacement

rad – radian

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