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Kinematic analysis of slider crank mechanism with joint clearance

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ABSTRACT

The slider-crank mechanism is a particular four-bar linkage configuration that exhibits both linear and rotational motion simultaneously. The clearance at joints of the mechanism exists due to manufacturing errors, material deformation and abrasion. This clearance is an unavoidable matter and cannot be eliminated, since it permit the relative motion between joints and make them assemblage. This will lead to the motion deviating from ideal movements, reducing the kinematic accuracy of mechanical systems which leads to decrease in mechanical performance. The objective of this paper is to analyze the effect of joint clearance on the kinematics of Slider Crank Mechanism. A functional model of crank mechanism in ADAMS/View software is developed to study kinematics. Joint clearance is considered at joints between crank-connecting rod and connecting rod-slider. These are simulated with set of different clearances for kinematical analysis. The results are validated experimentally on a Slider Crank Mechanism model manufactured with different joint clearances. This will give understanding of the deviation of mechanism from the actual path.

Keywords— **ADAMS/View , Joint Clearance, kinematic analysis, Slider crank mechanism.**

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I. Introduction

The slider-crank mechanism is a four-bar linkage mechanism that gives both linear and rotational motion. Internal combustion engines are example of this mechanism. The position, velocity, acceleration by a slider-crank mechanism during operation can be determined analytically[3]. In most cases, the joints of the mechanism exists clearance due to manufacturing errors, material deformation and abrasion. The joint clearances that exists in the mechanism leads to motion deviating from ideal movement[6], reducing the kinematic accuracy of mechanical system and this situation leads to decrease in mechanical performance. Joint Clearance gives variation in actual position of slider crank mechanism causing results differ from experimental data. In order to study the output movement error of the slider-crank mechanism with clearances, the kinematic equation and experimental model is established.

The rapid development of computer technology allowed the development of different kinds of simulation software. Computer simulation can be solved a wide range of very difficult kinematic tasks. A computer model is compiled on the basis of mathematical analysis, defining the model having the properties of a real object. MSC ADAMS / View contain a specialized environment for creating virtual objects consisting of rigid and deformable parts linked to each other with different kinematic joints. This allows creating static, kinematic and dynamic analysis of virtual prototypes by computer simulation. The advantage is the compatibility with CAD file formats and the ability to import geometry directly into the ADAMS interface. We studied a functional model of a crank slider mechanism.

1.1 Joint Clearance in Slider Crank Mechanism:

The joint clearance is the difference of the diameters of the pin and hole of a joint. Fig.1.1 shows the enlarged view clearance link (c), which is a mass-less link. Minimum 15 to 25 microns clearance is required for assembly and to have relative motion between parts. In a revolute joint, joint clearance 'c' is defined as the difference between the radii of bearing and journal, rB and rJ, respectively. The clearance can be defined as, c = rB – rJ. Each joint clearance adds additional degree of freedom to the mechanism, and additional constraints are necessary to analyze the system. With the development, the operating speed and load capacity of the slider-crank mechanism is been put forward higher requirements. In most cases, the joints of the mechanism exists clearance due to manufacturing errors, material deformation and wear. The clearance lead actual movement deviate from ideal movement of the mechanism and cause error in system, and this situation decreases mechanical performance of mechanism. Mechanisms consist of several links, considered rigid bodies and joints connecting these links in order to transmit motion or forces from one to adjacent link. In a planar revolute joint, as shown in Fig.1.2, joint clearance rC is defined as the difference between the radius of bearing and journal, rB and rJ respectively. As seen in Fig.1.2, the equivalent clearance can be defined in the following form, rc = rB − rJ . Each joint clearance adds additional freedom to the mechanism, and additional constraints are necessary to analyze the system.

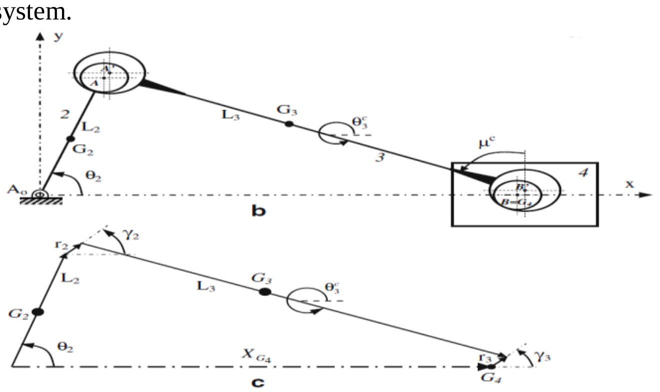


Fig.1.1. schematic representation of a slider-crank mechanism with joint clearances, c. vector representation of mechanism [5]

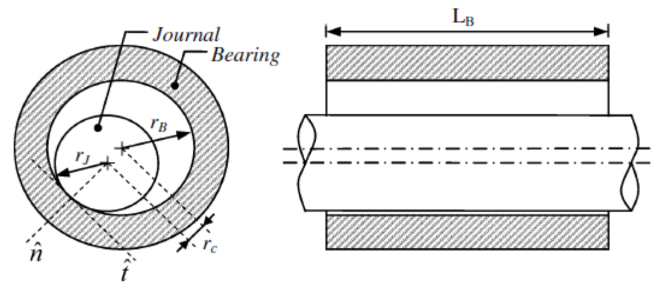


Fig 1.2: Revolute joint with clearance[5]

1.2 METHODOLOGY:

The planned methodology for the project implementation is as follows:

The rapid development in manufacturing increases requirements for faster production with greater accuracy at the lowest possible cost. This is associated with rising demands of customers, market condition but mainly by globalization, to fulfill these increasing demands some new, faster and more efficient methods for solving complex problems must be found. The rapid development of computer software allowed the development of different kinds of simulation .Computer simulation can solved a wide range of difficult kinematic tasks. A computer based model is compiled on the basis of mathematical analysis, defining the model having the properties of a real object. Since the created model has the same characteristics as the actual object, the computer simulation gives the same results as the actual simulation model. Process used is as follows:

Study of different parameters for Slider Crank Mechanism. Modeling and Simulation of slider crank mechanism using ADAMS with and without joint clearance. Fabricate a working model of a slider crank mechanism with joint clearance. Experimental Validation of results.

II. MATHEMATICAL MODEL

Kinematics of slider crank mechanism is studied by preparing mathematical model [I] for slider crank mechanism without joint clearances.

2.1.1. Displacement of Piston:

Figure shows slider crank mechanism in which crank OA rotates in clockwise direction. l and r are the length of connecting rod and crank respectively.

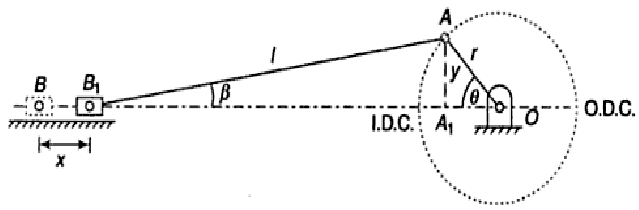


Fig 3.1.1. Kinematics of Slider Crank Mechanism

X=B1B=BO-B1O

X= $r[(1-\mathrm{COS}\theta)+(n-\sqrt{n^2-(\sin\theta)^2}\,]$ ..Eq.[i]

Where X is displacement of piston from IDC,

n=Obliquity Ration = (l/r)

θ= Input angle of crank

w=angular velocity of piston (rad/s)

2.1.2. Velocity Of piston:

V=$r\omega[\sin\theta+\frac{\sin 2\theta}{2\sqrt{(n^2-\sin\theta^2)}}]$ ….If n^2 is too large then,

V=$[r\omega(\sin\theta+\frac{\sin 2\theta}{2n})]$ ….. eq.[ii]

If $\frac{\sin 2\theta}{2n}$ can be neglected (when n is quite large)

V= $r\omega\sin\theta$

2.1.3. Acceleration of piston:

F = $\frac{dv}{dt}=\frac{dvd\theta}{d\theta dt}$

$=\frac{d}{d\theta}\left[r\omega\left(\sin\theta+\frac{\sin 2\theta}{2n}\right)\right]\omega$

$=r\omega^2(\cos\theta+\frac{\cos 2\theta}{n})$ ………….eq.[iii]

If n is very very large,

f $=r\omega^2\cos\theta$ as in case of SHM

III.MODELLING AND SIMULATION OF SLIDER CRANK MECHANISM WITHOUT CLEARANCE

ADAMS stands for Automatic Dynamic Analysis of Mechanical Systems at University of Michigan, MI, USA. ADAMS/View was released which allowed users to build, simulate and examine results.

3.1. Slider-Crank Mechanism Kinematics:

The parameters of Slider-Crank mechanism are stated as follows: Given l1, l2 , l3 , μ ,m1 ,m2 ,m3 ,θ1 are length , poisons ratio masses and angular position and angular velocity w. A Slider-Crank mechanism is built in MSC

ADAMS/View. Lengths are applied to all three links as given,a rotational motion is applied on link1. During the simulation, link1 will rotate 300 around origin. The accelerations in x direction at the centre of the slider are measured in MSC ADAMS/View.

3.2. Modelling of Slider Crank Mechanism without Clearance:

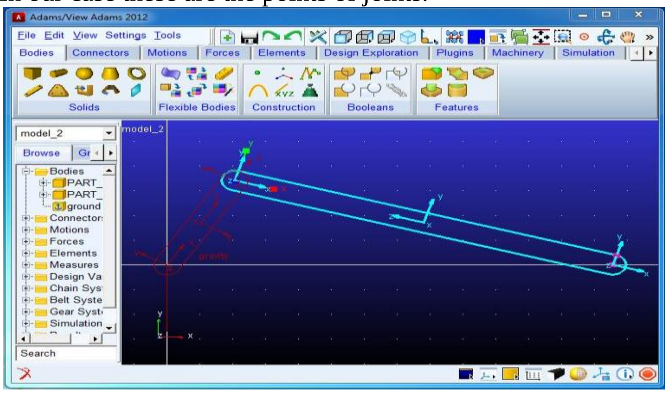
The Slider-Crank Mechanism model is built in following steps: First open MSC ADAMS/View, click “new model”, in the “Create New Model” , select “gravity”, “Units” and “Working Directory”, then press “OK”. In the whole modeling process, the rigid bars are first built. Link 2 and link 3 are built horizontally according to the dimensions. Joint1 connects the ground and link2. Links are built using “Bodies” tab, solids library. Then link3 is rotated around joint2 to the position as follows; link4 is built according to the known dimensions in other places and then is translated to joint3. At joint3 both revolute joint and prismatic joint are applied. All the joints can be found under the “connectors” tab. Link 4 and ground are connected with prismatic joint. The Slider-Crank mechanism is driven by the rotational motion at Joint 1. The slider is moving from right to left and then back according to the rotation. The rotational motions at joint 2 will be found in simulation with w2 = 30 rad/s , and the motions will be exported as numerical data and be saved as test files in computer.

3.2.1.Model in MSC Adams:

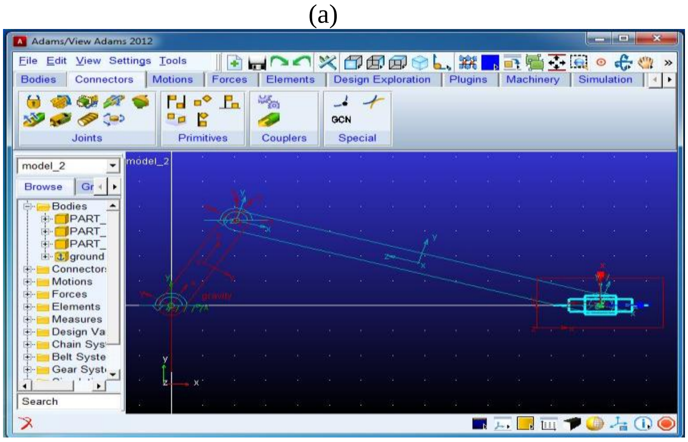
Here we describe the compilation of MSC Adams model of slider crank mechanism. This procedure consists of several steps. The assembled model will be ready to simulate the movement of the mechanism to be analyzed.

3.2.2. Members of the crank slider mechanism:

Individual members of mechanisms are created in the plane by marking the essential key points, so called design points. In our case these are the points of joints.



(a)



(b)

Fig .3.2.2. Creating members of the crank slider mechanism (a) member two and three and (b) member two, three and four.

The next step is the modelling of members of the crank slider mechanism. From main window select Toolbox to insert a solid body . Enter the width and thickness of the given member. By clicking left button we place the member connecting first and the second point. Another member is also created by combining the second and the third point. Modelling the individual members of the mechanism is shown in Fig 3.2.2.

3.2.3. Determining the links and motion:

To enable the links movement the linkages must be defined for their respective joints. They define the relative positions of the two bodies. There are revolute joints between links of the crank mechanism. In the table for determining link properties select the option for determining the joint by a defined point. Motion is defined by clicking the left mouse button on the first design point, so that the first member will rotate about the first design point. The second link is at the second design point, which produces the rotational joint between members. Last revolute joint is placed in the third design point (Fig 3.2.3).

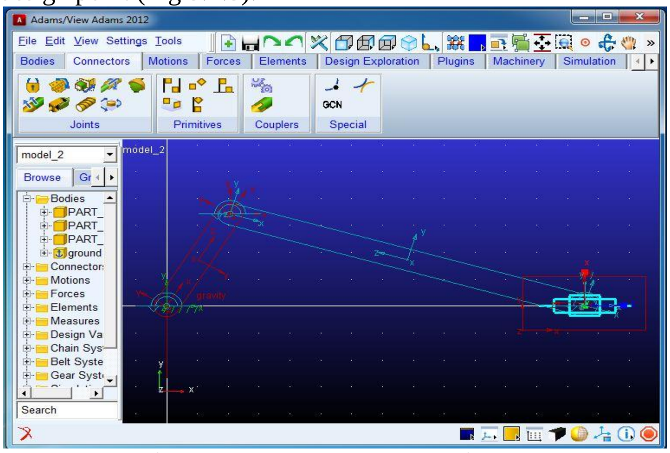


Fig 3.2.3: Defining the joints between members of the crank slider mechanism for rotational and translational joint.

3.2.4.Modelling of the contact:

For the modelling of the contact under ADAMS, we have used the contact method based on the impact function, IMPACT-Function-Based Contact. In this method, ADAMS/Solver computes the kinematics from the IMPACT function available in the ADAMS function library. From the simulations, ADAMS/Solver can give a continuous flow of responses, including accelerations, velocities, positions and forces from all the elements and points of contact.

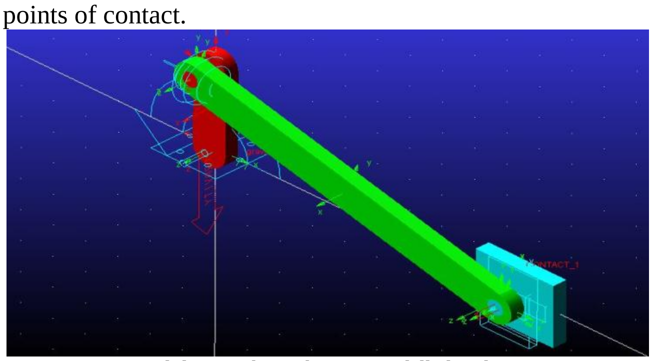


Fig. 3.2.4. Slider–crank Mechanism modelled under ADAMS.

IV.EXPERIMENTAL SETUP

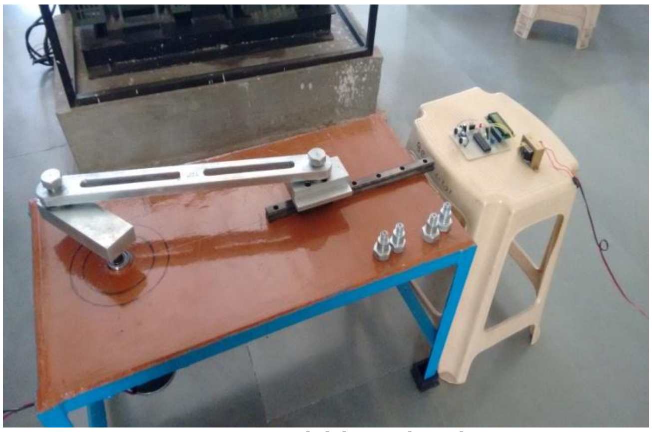


Fig. 4.1 Experimental slider-crank mechanism

This section describes the experimental test rig constructed for kinematic analysis of slider crank mechanism. Figure 4.1 shows an overall view of the experimental apparatus of the slider-crank mechanism, in which the revolute joint that connects the crank and connecting rod and the slider and connecting rod has a variable radial clearance. This type of joint was used due to its simplicity and importance in the field of machines and mechanisms. This joint was designed as a dry journal-bearing. The remaining kinematic joints were constructed as close to the ideal joints as possible, that is, with minimum clearance and friction in order to minimize error in the data that were focused to be measured. Moreover, these joints were lightly oiled to minimize the friction in their connections. The pin element was threaded to the extremity of the crank and slider working as links. The pin was rigidly connected to the sliding block with a variable diameter. Thus, the clearance at joints can be altered by simply changing the pin. The crankshaft was keyed to the crank and it was supported by ball bearings. A revolute joint, with radial clearance connects the crank to the connecting rod. The sliding block component is screwed onto a linear translational bearing, which has a precision preloaded system with zero-clearances. Table I shows the Clearance of joints used in the experimental slider-crank mechanism. Thus, for numerical purposes, they can be considered as ideal or zero-clearance joints.

TABLE I

The slider-crank mechanism works on the horizontal plane and, due to its rigidity and alignment, the gravitational effects on the system’s dynamic responses can be neglected. The mechanism components were built entirely from steel and, hence for practical purposes, were assumed to be perfectly rigid. The connecting rod was built with a hollow cross-section in order to reduce the mass, while maintaining a high stiffness and, thus, reducing the flexibility effects. The slider-crank mechanism and all other mechanical components were mounted on a heavy stiff frame. The overall mass of the experimental equipment, including frame and moving parts, was about 45 kg .The test rig is used to study the response of the systems for a varying clearances between the connecting rod and the slider and crank and connecting rod.

Fig.4.2. Pins used with varying diameter in slider-crank mechanism

The pin element was threaded to the extremity of the crank and slider working as links. The pin was rigidly connected to the sliding block with a variable diameter. Thus, the clearance at joints can be altered by simply changing the pin. The crankshaft was keyed to the crank and it was supported by ball bearings. A revolute joint, with radial clearance connects the crank to the connecting rod. The sliding block component is screwed onto a linear translational bearing, which has a precision preloaded system with zero-clearances.

V.RESULT & DISCUSSION

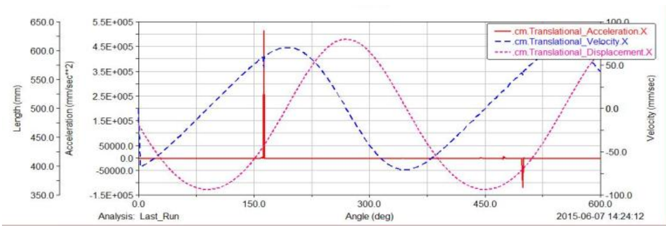


Fig 5.1. acceleration,velocity and acceleration with pin 22 mm

Figure shows displacement ,velocity and acceleration versus crank rotation (angle).

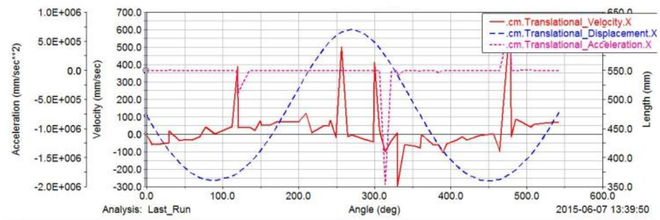


Fig.5.2. acceleration,velocity and acceleration with pin 23 mm

Pin (I)	Crank and pin(I) (mm)	Pin(II)	Slider and pin(II) (mm)
22	1.00625	22	1.0025
23	0.49875	23	0.50125
24	0.00625	24	0.00125

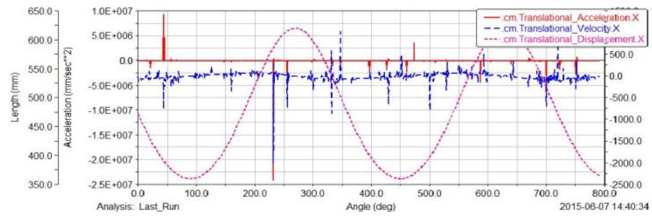


Fig 5.3 acceleration,velocity and acceleration with pin 22 mm

VI.EXPERIMENTAL DETAILS

TABLE II Simulation results:

Pin	Displacement(mm)		Velocity(mm/s)		Acceleration(mm/sec²)	
	max	min	max	min	max	min
22 mm pin	620.2597	359.593	1022.3722	-2012.1473	9.3419*10^6	-2.4132*10^7
	260.6667					
23 mm pin	620.3896	360.3144	652.1874	-295.1338	8.6099*10^5	-1.9587*10^6
	260.0752					
24 mm pin	620.002	359.9979	70.4698	-70.4698	5.1457*10^5	-1.1836*10^5
	260.0041					
Ideal	623.4192	363.4192	70.409	-70.409	26.2042	-45.0766
	260					

Table shows variation in displacement ,velocity and acceleration with respect varying joint clearance. This results will be validated experimentally.

VII.CONCLUSION

Modeling and Simulation of slider crank mechanism in ADAMS gives results of position, velocity and acceleration of slider without clearance .In this Paper we studied the kinematic behavior of a planar flexible slider–crank mechanism with clearance. The obtained results, based on the model of impact used in ADAMS, highlight the effect of the clearance in the joint on the mechanism performances. From the obtained result it shows that with increase in clearance value the impact force increases drastically and it results into increase in displacement , velocity and acceleration values .

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