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Analysis of Position Error in Offset Slider Crank Mechanism

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Abstract

Four-bar linkage mechanisms have attracted much attention for the mobility of equipment's and devices. The offset slider crank mechanism is an inversion of four-bar mechanism, where the slider will move at a offset distance from the rigid link. In the assembly and mobility of heavy equipment such as satellites, offset slider crank mechanism is used as ground support equipment. In this study, the mechanism is analyzed for the influence of deviations in input parameters on mechanical performance. The slider position depends on the crank angle (Ø), crank length (*l*), the connecting rod length (*r*) and slider offset (e). The error in the slider displacement with variable input parameters was expressed analytically and solved using the MAT LAB program. The result can depict the error in slider displacement and the quantification of the input error on it. Thus, it highlights the influence of input parameters and facilitates in predicting the effective and precise motion of the mechanism.

Keywords: *Slider crank mechanism, displacement error, error analysis, MAT LAB.*

1.0 Introduction

The slider-crank mechanism is commonly found in vibrating sieves, internal combustion engines, and stamping machines to transform rotation to linear motion that can convey force or motion[1]. As modern industry has grown, the operating speed and load capacity of the slider-crank mechanism has become more demanding[2]. Because of manufacturing flaws, material deformation, and abrasion, the joints of a mechanism usually have clearance[3]. The clearance causes the actual movements of the mechanism to deviate from its ideal movements, resulting in an impact dynamic load, particularly in high-speed mechanisms, and this scenario decreases mechanical performance. Numerous designers are investigating the effects of joint clearance on various mechanical systems. Flores et al. developed a method for mechanism analysis using joint clearance and used it to analyze a slider-crank mechanism having a single joint clearance between the piston and connecting rod[4]. Erkaya et al. examined the dynamic properties of an special slider-crank mechanism with an supplementary eccentric link between the connecting rod and crank[5,6]. Using the concept of virtual displacement and optimization, Sun et al. discussed the relationship between the original error and pose error for the output end of a planar mechanism and presented a mathematical model of the pose error for the output end[7]. The motion gets deviated because of the clearances existing at the joints.

In addition, the input parameter deviation will contribute to the displacement error of the output. According to the application and constraint characteristics, the four-bar mechanism is used in different forms as its inversions. The four-bar linkage tilting system works on the principle of the slider crank mechanism[8]. For the four-bar linkage tilting system, the position error analysis is necessary to derive the relation between the mechanism parameters (geometric and kinematic) and the slider displacement[9]. This analysis quantifies the displacement error of the mechanism due to the

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errors in mechanism parameters.

Additionally, the kinematic analysis of the mechanism will determine the velocities and accelerations of mechanism points and the angular velocities and accelerations of links. It entails determining the primary and secondary derivatives with respect to time for coordinates and their derivatives given as inputs[9] Consequently, the analysis of position error is also required for the kinematic synthesis of mechanisms. In this study, mathematical equations were derived to calculate the deviation of the output (slider) displacement caused by geometric and kinematic errors in the mechanism's linkages.

2.0 Mechanism Errors

Errors in the mechanism are the deviance of tangible mechanism parameters from the projected values. Geometric errors and kinematic errors are the most likely reasons for mechanism errors. Geometric errors are the deviance of the constant geometrical parameters (link dimensions) of a mechanism from their minimal values. The kinematic errors are the deviations $\Delta q1$, $\Delta q2$, $\Delta q3$,... qn of the input parameters from their original values.

Most of the errors are attributed to the production and assembly of mechanisms, as well as the use of mechanisms. The determination of partial derivatives of position functions is required when parametrically analysing mechanisms. The partial derivatives of position functions with respect to

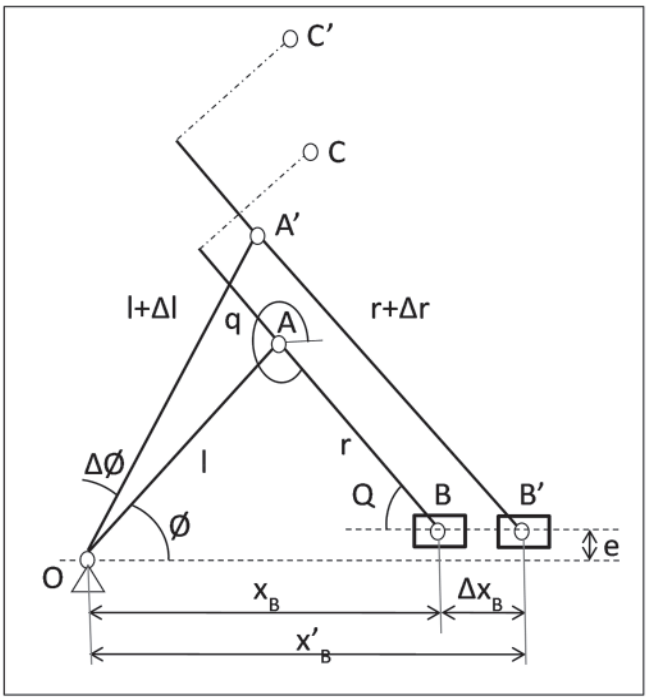

Figure 1: Offset slider-crank mechanism

constant mechanism parameters must be determined (link lengths, coordinates of joints etc). For the accuracy study of this mechanism, partial derivatives are necessary.

The primary errors lead to deviations in the positions of the output links between the actual mechanism and its ideal counterpart. These variations are known as position errors. Figure 1 depicts the position error $x_B = x'_B – x_B$ of point B of the slider crank mechanism, which is caused by errors l and r in the lengths of the crank and connecting rod, respectively, and a kinematic error. Point C represents the centre of gravity of the spacecraft. Displacement error refers to the difference between the displacements of output links of actual and idyllic mechanisms. Displacement error is the deviation at the position of the output link at the beginning and end of the mechanism's motion.

The position error analysis of the existing slider crank mechanism with known primary errors was performed using equation (1). This involves the partial derivatives of the mechanism[10].

$$\Delta x_r = \sum_{k=1}^{n} \frac{\partial \pi_r}{\partial q_k} \Delta q_k + \sum_{f=1}^{l} \frac{\partial \pi_r}{\partial \alpha_f} \Delta \alpha_f$$

(r = 1, 2, 3..., m) ... (1)

Where,

Δx_r – Position error

αf – Constant geometricparameters

q_k – Input coordinates

The analytical method for determining mechanism errors relies on equation (1). A structural transformation of the mechanism must determine the partial derivatives of group coordinates with respect to a particular parameter.

From the geometric analysis, equations for slider displacement and slider offset were obtained as shown in Figure 2.

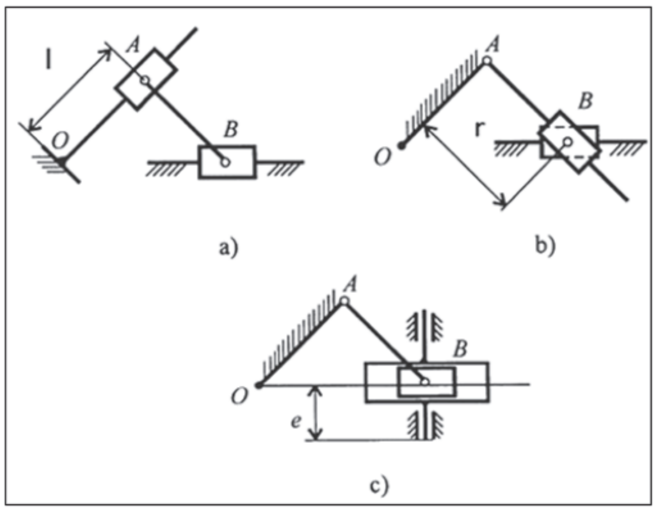

Figure 2: Structural transformations of the slider crank mechanism

$x_B = r \cos q + 1 \cos Ø$
$e = r \sin q + 1 \sin Ø$ ... (2)

For determining the partial derivatives, the above equations of slider displacement (x_B) and slider offset (e) are differentiated as follows;

with respect to q:

$$\frac{\partial x_B}{\partial q} + l \sin Ø \frac{\partial Ø}{\partial q} = -r \sin q$$

$$-l \cos Ø \frac{\partial Ø}{\partial q} = r \cos q$$

With respect to r (Fig.2 a):

$$\frac{\partial x_B}{\partial r} + l \sin Ø \frac{\partial Ø}{\partial r} = \cos q$$

$$-l \cos Ø \frac{\partial Ø}{\partial r} = \sin q$$

With respect to l (Fig.2b):

$$\frac{\partial x_B}{\partial l} + l \sin Ø \frac{\partial Ø}{\partial l} = \cos Ø$$

$$-l \cos Ø \frac{\partial Ø}{\partial l} = \sin Ø$$

with respect to e (Fig.2c):

$$\frac{\partial x_B}{\partial e} + l \sin Ø \frac{\partial Ø}{\partial e} = 0$$

$$-l \cos Ø \frac{\partial Ø}{\partial e} = -1$$

After simplification,

$$\frac{\partial x_B}{\partial q} = r\, l \sin(Ø - q)/J \qquad \frac{\partial Ø}{\partial q} = -r \cos q/J$$

$$\frac{\partial x_B}{\partial r} = l \cos(q - Ø)/J \qquad \frac{\partial Ø}{\partial r} = -r \sin q/J$$

$$\frac{\partial x_B}{\partial l} = l/J \qquad \frac{\partial Ø}{\partial l} = -\sin Ø/J$$

$$\frac{\partial x_B}{\partial e} = -l \sin Ø/J \qquad \frac{\partial Ø}{\partial e} = 1/J$$

With this position error of the system is,

$$\Delta x_B = l[r \sin(Ø - q)\Delta q + \cos(q - Ø)\Delta r + \Delta l - \sin Ø \,\Delta e]/J \quad \text{... (3)}$$

3.0 Results and Discussion

Substituting the values of mechanism parameters r (column length), l (crank length), Ø (crank angle) and q (angle at the column hinge measured in counter clock wise direction to the column) and primary errors in the column length, crank length, input angle and offset distance i.e.; Δr, Δl, Δq and Δe, respectively, the error in the slider displacement (x_B) is calculated using equation (3) for various angles of Ø from 10.27° to 52.27° as shown in Table 1. The position error calculation in the displacement of the slider was performed using the MAT Lab program. The MAT Lab program.

The variation of slider displacement error (ΔxB) due to error in column length (Δr) is plotted with respect to crank angle (Ø) as shown in Figure 3.

The variation of slider displacement error (ΔxB) due to error in crank length (Δl) is plotted with respect to the crank angle (Ø) as shown in Figure 4.

The variation of slider displacement error (Δx_B) due to error in offset distance (Δe) is plotted with respect to crank angle (Ø) as shown in the Figure 5.

Table 1: Position error calculation

Q°	Ø°	x_B, mm	Δr=0.1%	Δl=0.1%	Δe=0.1%	ΔQ =0.1°	Δ=0.1%
			Error in slider displacement (Δx_B), mm				
11.16	10.27	3144.67	1.32	1.82	-0.009	5.52	8.66
22.41	18.92	2996.99	1.11	1.9	-0.017	10.05	13.04
33.66	27.31	2764.58	0.76	2.02	-0.025	13.69	16.46
41.16	32.66	2569.38	0.46	2.13	-0.032	15.51	18.08
52.41	40.09	2230.92	-0.08	2.35	-0.042	17.13	19.36
63.66	46.45	1861.29	-0.69	2.61	-0.052	17.22	19.08
74.91	51.14	1493.7	-1.313	2.86	-0.062	15.66	17.16
86.16	53.49	1164.55	-1.79	3.02	-0.067	12.7	13.87
97.41	53.04	901.69	-2.02	2.99	-0.066	9.185	10.08
101.16	52.26	830.65	-2.04	2.94	-0.064	8.06	8.89

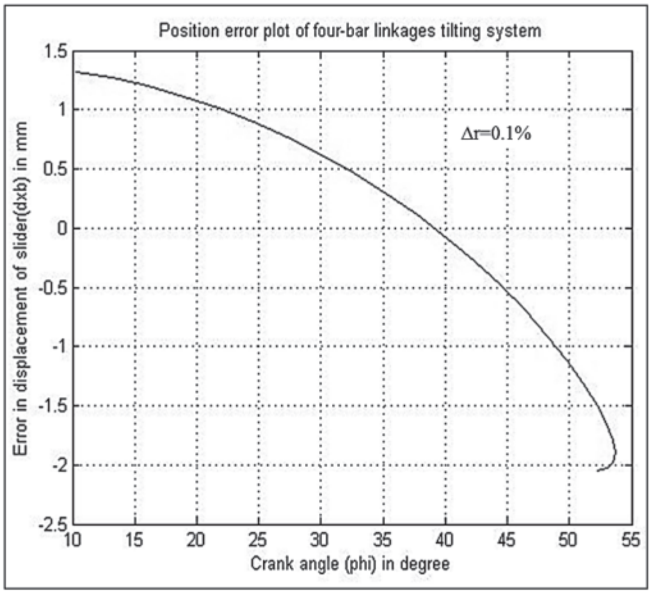

Figure 3: Crank angle (Ø°) v/s error in slider displacement (ΔxB) (for Δr=0.1%)

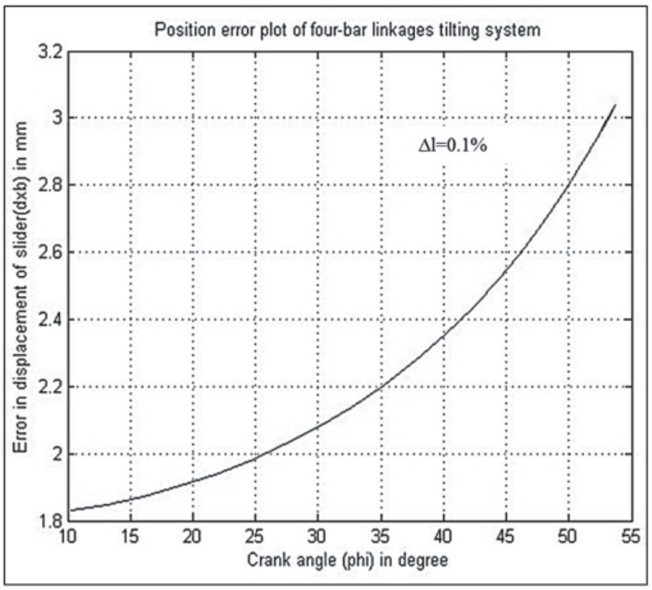

Figure 4: Crank angle (Ø°) v/s error in slider displacement (ΔxB) (Δl=0.1%)

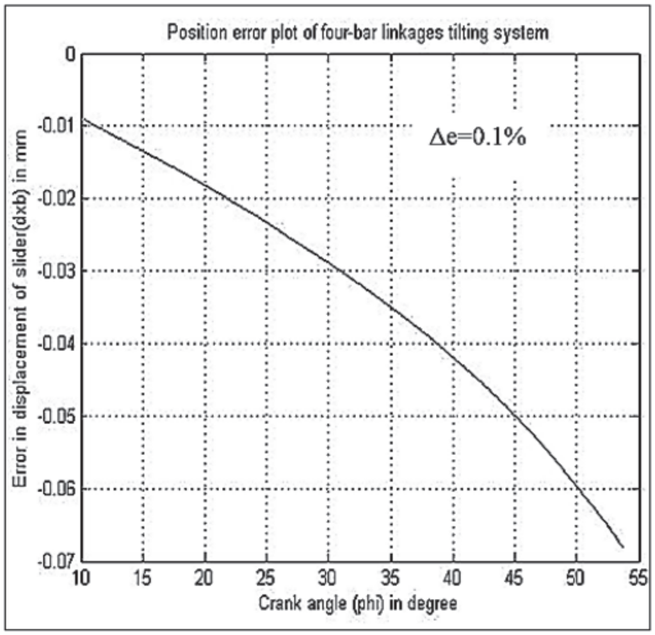

Figure 5: Crank angle (Ø°) v/s error in slider displacement (ΔxB) (for Δe=0.1%)

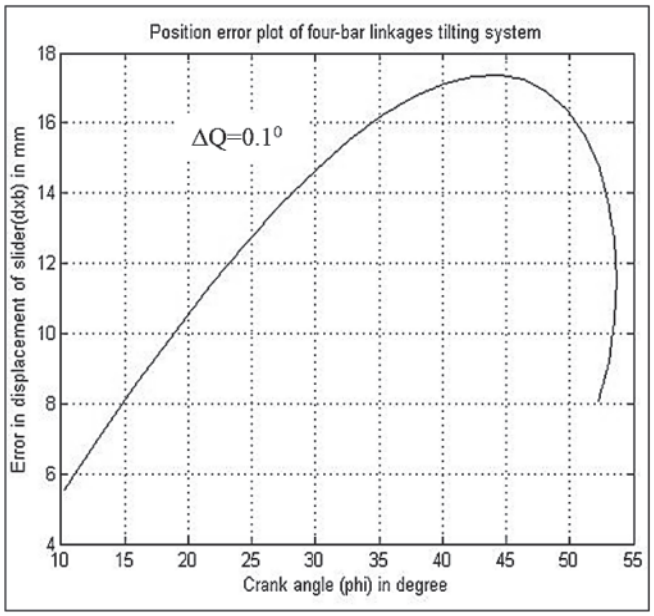

Figure 6: Crank angle (Ø°) v/s error in slider displacement (Δx_B) (for $\Delta Q = 0.1^0$)

The variation of slider displacement error (Δx_B) due to error in column angle (ΔQ) is plotted with respect to crank angle (Ø) as shown in the Figure 6.

The variation of slider displacement error (ΔxB) due to errors in column, crank, offset, column angle (Δ=0.1%) is plotted with respect to crank angle (Ø) as shown in Figure 7.

The plots of crank angle (Ø) v/s error in slider displacement (Δx_B) due to error in each parameter like column length (Δr), crank length (Δl), column angle (Δq) and offset distance (Δe) considering eachat once reveals the significance of error in each parameter on the error in slider displacement (Δx_B). From the error plots, it can be observed that the error in the input angle (q) has the highest effect and the error in offset distance (Δe) has the least effect on slider displacement $x_{B.}$ Also, the error in crank length (Δl) and column length (Δr) have significance effect on $x_{B.}$

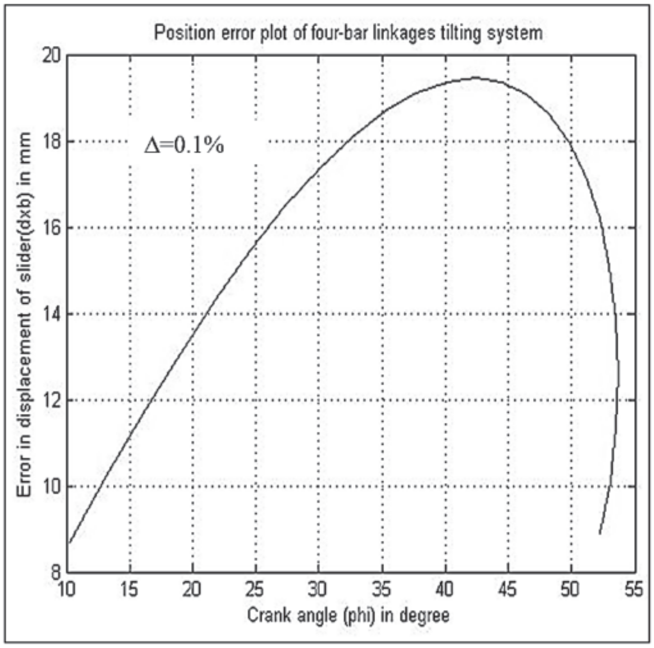

Figure 7: Crank angle (Ø°) v/s error in slider displacement (ΔxB) (for Δ=0.1%)

4.0 Conclusion

In this study, we consider the conditions of the offset slider crank mechanism to evaluate the error in slider displacement induced to the geometric error in the linkages. The position error analysis for the offset slider crank mechanism reveals that the errors in kinematic parameters (crank angle) will cause more error in the slider displacement. The constant geometric parameters will have their contribution to the displacement error in decreasing order starting from the crank radius, connecting rod length and slider offset distance.

The optimization of the mechanism's design parameters using software such as ADAMS can effectively reduce position error and improve the precision of mechanical motion and force transmission efficiency.

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