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Design and DMU Kinematic Analysis of Slider Crank Mechanism Using CATIA and MATLAB

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***Abstract*–The slider-crank mechanism is a particular four-bar linkage configuration that exhibits both linear and rotational motion simultaneously. A CAD model has been prepared in CATIA V5 to simulate the mechanism and to specify the accurate path of the mechanism. Also the analytical method which can be used to define the various position of crank and respective position of slider in Slider Crank mechanism is discussed. MATLAB programs are provided for kinematic analysis of a Slider Crank mechanism containing a coupler point. The program performs position, velocity, and acceleration analysis for a given angle of the crank. The program solves for the unknown coordinates, velocities, and accelerations. Finally the reports of the results are in numerical form. The analysis based on the mathematical model performed with the help of MATLAB.**

***Keywords*–Slider Crank mechanism, CAD model, Position analysis, MATLAB**

I. INTRODUCTION

Mechanisms are used in variety of fixed motion generation applications in Engineering. Among that slider crank mechanism is most useful mechanism in the present day application for internal combustion engines and numerous other applications such as robotics, pumps and compressors. A Slider Crank Mechanism is a modification of four bar chain. It consists of one sliding pair and three turning pairs. It is usually found in Reciprocating Steam engine mechanism. This type of mechanism converts rotary motion into reciprocating motion and vice versa. However when it is used as an automobile engine by adding valve mechanism etc., it becomes a machine which converts the available energy (force on the piston) into the desired energy (torque of the Crank shaft). The torque is used to move a vehicle. Reciprocating pumps, Reciprocating compressors and steam engines are other examples of machines derived from the slider crank mechanism.

II. SLIDER CRANK MECHANISM

Algorithm for Kinematic analysis following in MATLAB
Slider crank mechanism modeling
Position analysis of four bar slider crank mechanism

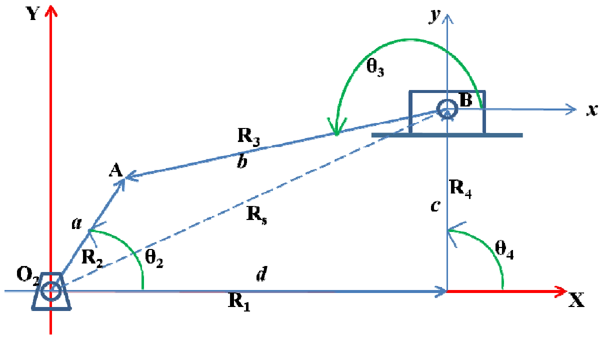

Fig. 1 Position vector loop for a four bar slider crank linkage

The linkage could be represented by only three position vectors, R2,R3 and Rs but one of them(Rs) will be a vector of varying magnitude and angle. It will be easier to use four vectors R1, R2, R3, R4 with R1 arranged parallel to the axis of sliding and R4 perpendicular. In effect the pair of vectors R1 and R4 is orthogonal components of the position vector Rs from the origin of the slider. It simplifies the analysis to arrange one coordinate axis parallel to the axis of sliding. The variable Length, constant direction vector R1 then represents the slider position with magnitude d. The vector R4 is orthogonal to R1 and defines the constant magnitude offset of the linkage.

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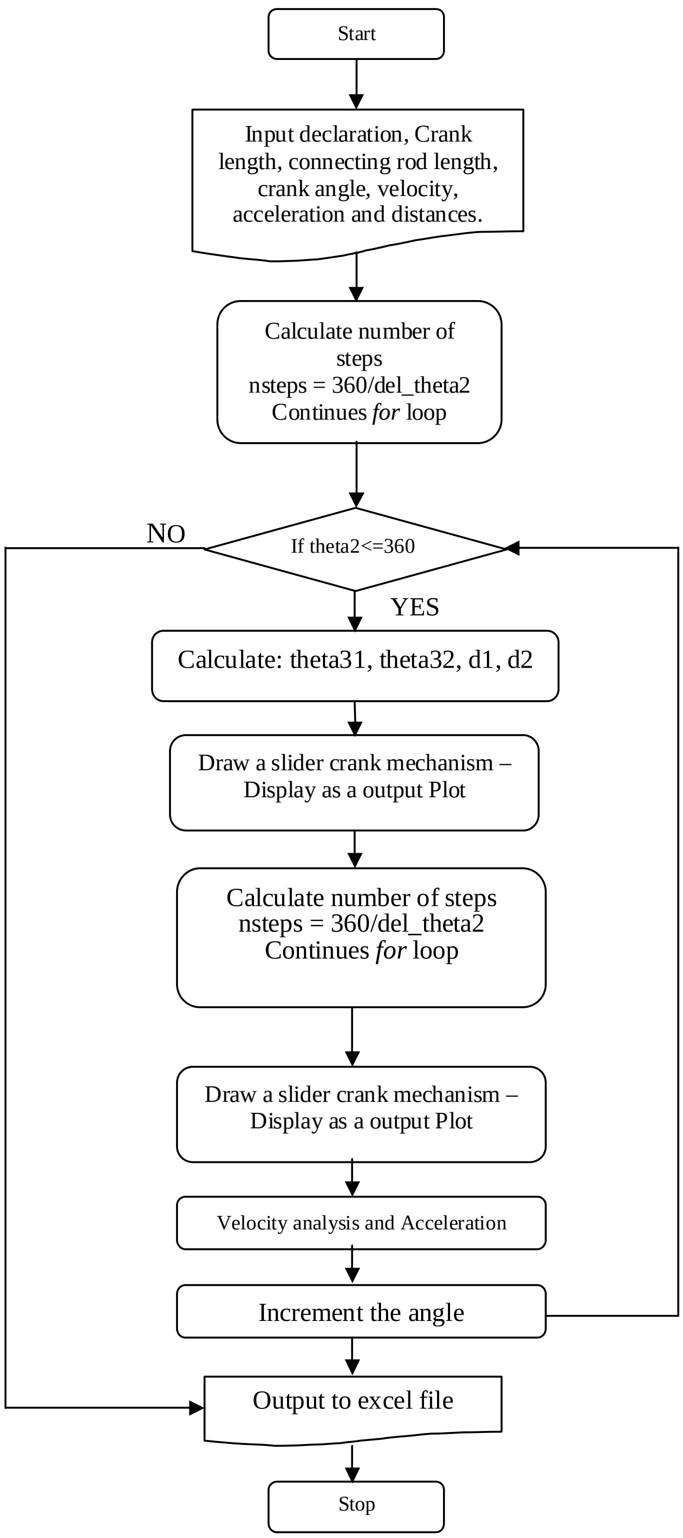
The Vectors R_2 and R_3 complete the vector loop. The coupler's position vector R_3 is placed with its root at the slider which then defines its angle θ_3 at Point B. This particular arrangement of position vectors leads to a vector loop equation similar to the pin-jointed four bar example: The angle θ_3 must always be measured at the root of vector R3.

Fig. 2 Slider crank mechanism



$$R_2 - R_3 - R_4 - R_1 = 0 \text{ ------- (1)}$$

$$ae^{j\theta_2} - be^{j\theta_3} - ce^{j\theta_4} - de^{j\theta_1} = 0 \text{ ------- (2)}$$

Substitute the Euler equivalents

$$a(\cos\theta_2 + j\sin\theta_2) - b(\cos\theta_3 + j\sin\theta_3) - c(\cos\theta_4 + j\sin\theta_4) - d(\cos\theta_1 + j\sin\theta_1) = 0 \text{ - (3)}$$

Real part (x) component

$$acos\theta_2 - bcos\theta_3 - ccos\theta_4 - dcos\theta_4 = 0 \text{ ------- (4)}$$

But $\theta_1 = 0$, so

$$acos\theta_2 - bcos\theta_3 - ccos\theta_4 - d = 0 \text{ ------- (5)}$$

Imaginary part (y) component

$$jasin\theta_2 - jbsin\theta_3 - jcsin\theta_4 - jdsin\theta_1 = 0 \text{ ---- (6)}$$

But $\theta_1 = 0$,and the j's divide out so

$$asin\theta_2 - bsin\theta_3 - csin\theta_4 = 0 \text{ ------- (7)}$$

Solving equations 5 and 7 simultaneously for finding the two unknowns such as link length d and link angle θ_3. The independent variable is crank angle θ_2. Link Lengths a and b the offset c and angle θ_4 are known.

$$\theta_{31} = arcsin\left(\frac{asin\theta_2 - c}{b}\right) \text{ ------- (8)}$$

$$d = acos\theta_2 - bcos\theta_3 \text{ ------- (9)}$$

There are two valid solutions corresponding to the two circuits of the linkage. The arcsine function is multivalued. Its evaluation will give a value between $\pm 90^0$ respecting only one circuite of the linkage. The Value of d is dependent on the calculated value of θ_3. The value of θ_3 for the second circuit of the linkage can be found from

$$\theta_{32} = arcsin\left(-\frac{asin\theta_2 - c}{b}\right) + \pi \text{ ------- (10)}$$

Velocity and acceleration analysis of four bar slider crank mechanism

Input angular velocity ω_2 applied to link2. This ω_2 can be time varying input velocity. Differentiating the equations with respect to time the length of link d varies. Substituent the Euler equation in the velocity vectors we get.

$$ja\omega_2(cos\theta_2 + jsin\theta_2) - jb\omega_3(cos\theta_3 + jsin\theta_3) - \dot{d} = 0 \text{ ------- (11)}$$

The term *d* dot is the linear velocity of the Slider block. The absolute velocity of Point A and the velocity difference of Point A versus Point B are

$$V_A = a\omega_2(-sin\theta_2 + j\,cos\theta_2) \text{ ------- (12)}$$

$$V_{AB} = b\omega_3\,(-sin\theta_3 + jcos\theta_3) \text{ ------- (13)}$$

$$V_{BA} = -V_{AB} \text{ ------- (14)}$$

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Acceleration analysis is considered as input angular acceleration α_2 applied to link 2. This α_2 can be a time varying input acceleration differentiates the inversion equation with respect to time to get expression for acceleration in this inversion of the slider crank mechanism. Based on euler identity unknowns are solved. Real and imaginary components as above replaced with angular acceleration value.

$$\left(ja\alpha_2 e^{j\theta_2} + j^2 a\omega_2^2 e^{j\theta_2}\right) - \left(jb\alpha_3 e^{j\theta_3} + j^2 b\omega_3^2 e^{j\theta_3}\right) - \ddot{d} = 0 \text{ ------- } (15)$$

$$\propto_3 = \frac{a \propto_2 cos\theta_2 - a\,\omega_2^2\, sin\theta_2 + b\,\omega_3^2\, sin\theta_3}{b\, cos\theta_3} \text{ ------- } (16)$$

$$\ddot{d} = -a\alpha_2 sin\theta_2 - a\omega_2^2 cos\theta_2 + b\alpha_3 sin\theta_3 + b\omega_3^2 cos\theta_3 \text{- } (17)$$

III. COMPUTER AIDED MODELING

Although the dimensions of the components are irrelevant to the process (but not to the kinematic results), the tutorial details provide some specific dimensions making it easier for the reader to model the appropriate parts and to obtain results similar to those herein.

Where specific dimensions are given, it is recommended that you use the indicated values (in mm). Some dimensions of lesser importance are not given; simply estimate those dimensions from the drawing.

In CATIA, model four parts named base, crank, conrod, FixedLink and block as shown in Fig 3.

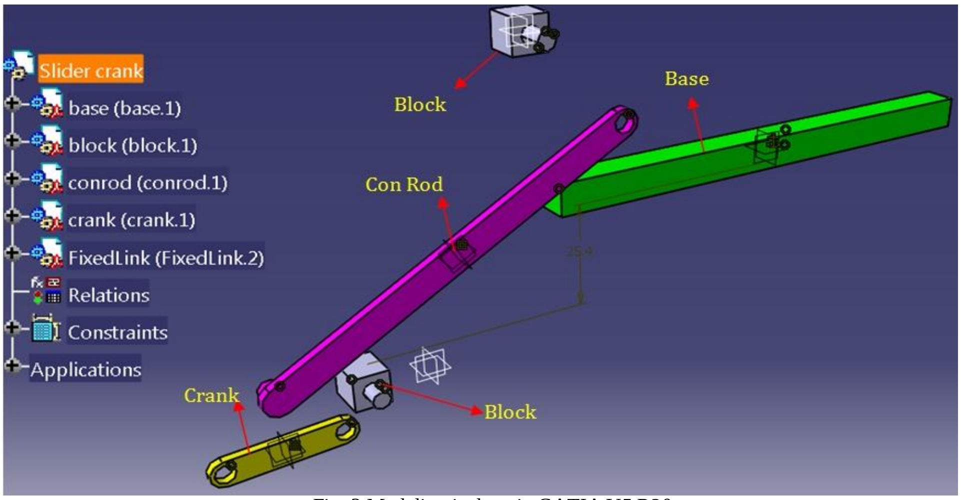

Fig. 3 Modeling is done in CATIA V5 R20

IV. KINEMATIC ANALYSIS IN MATLAB

In kinematic analysis, we determine the relative motion characteristics of a given mechanism. Broadly, we can classify the kinematic analysis problems into three headings namely, displacement analysis, velocity analysis and acceleration analysis. For all these three types of problems that are displacement analysis, velocity analysis and acceleration analysis, we can use either a graphical method or an analytical method.

In graphical method, there is an inherent limitation on the accuracy, because of the scale of the figure and your drawing inaccuracies. So, analytical method is preferred when we want higher accuracy. Or, if displacement analysis has to be carried on for a very large number of configurations and in the graphical method, the picture becomes really cumbersome. The other advantage of this analytical method is that, it is amenable to computer programming.

A. Basic Methodology of Analytical Analysis

- Identify all the independent closed loops that exist in the mechanism.
- Express all the kinematic dimensions like link lengths, offsets and also the slider displacement by planar vectors.
- Express Loop closed equation through these equations.
- Each such vector in 2D that is a planar linkage is equivalent to two scalar equations that means, if a vector equation is there, that is equivalent to two scalar equations and two unknown quantities can be solved.

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- Now, once these entire vector equations are generated using all the independent closed loops, one has to solve these equations to determine the unknown quantities that is relevant to your particular problem. One has to remember that in general, these equations are non-linear algebraic equations and can be solved only numerically. However, in such simpler cases, just like a 4R mechanism or if there is a four link closed loop, then we can show, that these non-linear algebraic equations, reduces to quadratic equation and can be solved analytically.

IV. RESULTS AND DISCUSSIONS

A. Analytical Results

The results are estimated for the four configurations of Slider crank mechanism for the below 4 configurations. The analytical Results are calculated.

TABLE I
SLIDER CRANK MECHANISM CONFIGURATIONS

Config-uration	a (mm)	b(mm)	c(mm) offset	θ_2 (Deg)	ω_2 (rad/Sec)	α_2 (rad/Sec^2)
1	35.66	101.6	25.4	45	10	0
2	76.2	203.2	50.8	-30	-15	-10
3	127	508	-127	225	-50	10
4	177.8	635	254	330	100	18

TABLE II
SLIDER CRANK MECHANISM ANALYTICAL RESULTS

Analytical Results								
Configuration	*θ3 Open (Deg)*	*Slider Open*	*θ3 crossed (Deg)*	*Slider crossed*	*ω3 (rad/Sec)*	*Slider Vel in m/s*	*α3 (rad/Sec2)*	*Slider Acc in m/s2*
1	180.1	127	-0.14	-76.2	2.47	-0.252	-25	-1.9
2	205.9	248.9	-25.9	-116.8	-5.42	-0.09	29	-12.4
3	175	416.6	4.2	-596.9	8.86	-4.161	447	281.8
4	212.7	688.3	-32.7	-378.5	28.8	-0.988	1136	-1484.1

V. MATLAB RESULTS

For the four configurations mentioned in Table I, four Input files prepared and MATLAB Program run for those configurations. The MATLAB Results are as follows:

TABLE III
SLIDER CRANK MECHANISM ANALYTICAL RESULTS

MATLAB Out Put								
Configuration	*θ3 Open (Deg)*	*Slider Open*	*θ3 crossed (Deg)*	*Slider crossed*	*ω3 (rad/Sec)*	*Slider Vel in m/s*	*α3 (rad/Sec2)*	*Slider Acc in m/s2*
1	180.144	126.744	-0.1439631	-76.45496	2.4748815	-0.252079	-24.764205	-1.88584787
2	205.944	248.712	-25.94448	-116.73	-5.417363	-0.089896	30.24	-12.3270379
3	175.801	416.834	4.1991444	-596.4389	8.8626259	-4.160461	447.125656	281.830683
4	212.684	688.437	-32.683639	-380.478	28.810407	-0.989088	1136.01422	-1484.11157

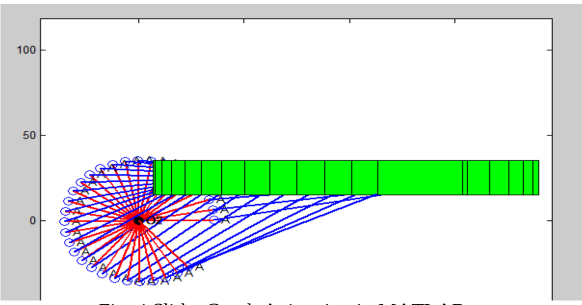

Fig. 4 Slider Crank Animation in MATLAB

A. Comparison between Analytical & MATLAB Results

The MATLAB Results and Analytical Results are compared. The Comparison for four configurations of slider crank mechanism are plotted in the following.

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Configuration 1:

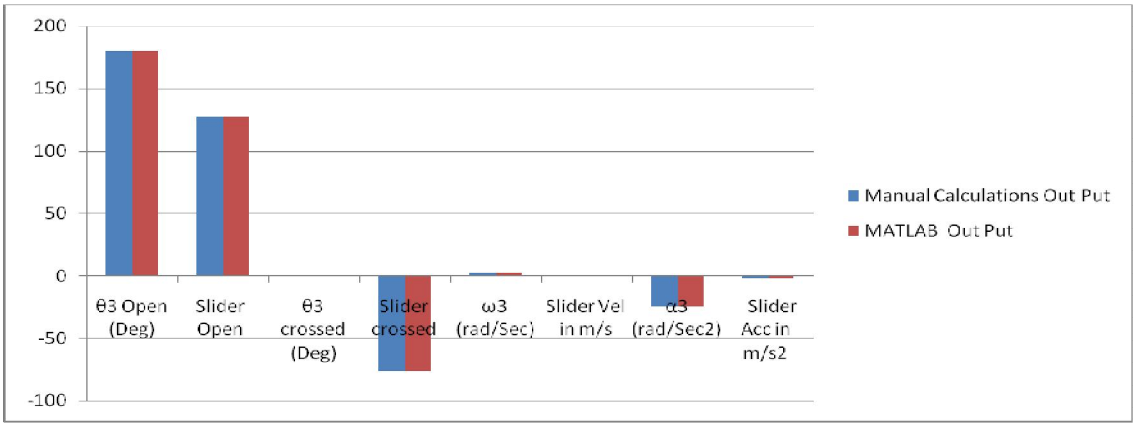

Fig. 5 Analytical Vs MATLAB Results for Configuration -1

Configuration 2:

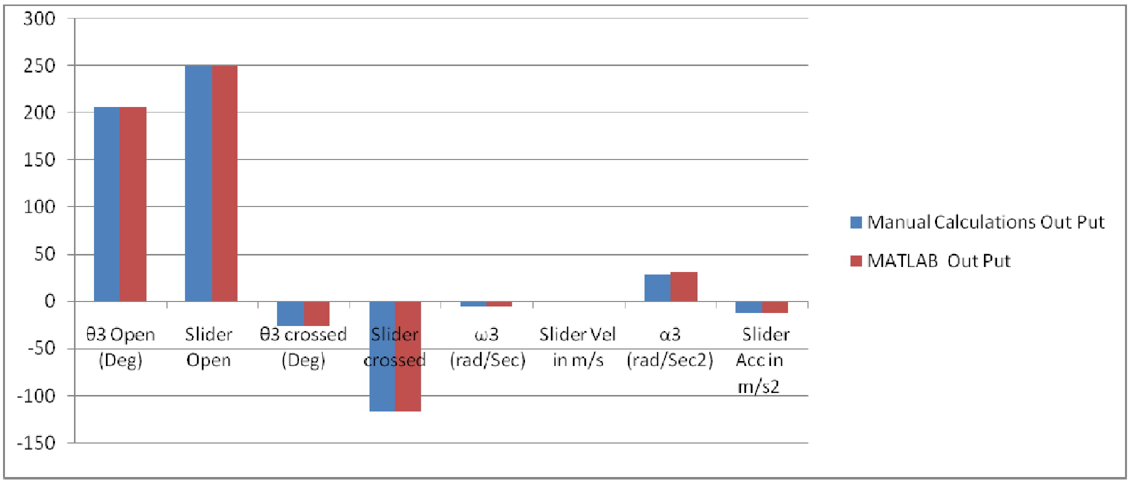

Fig. 6 Analytical Vs MATLAB Results for Configuration -2

Configuration 3:

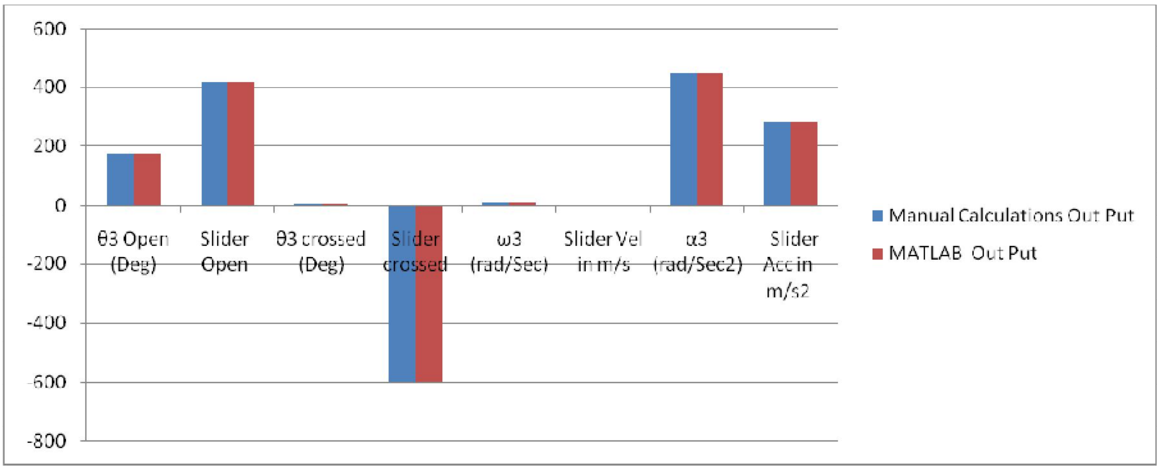

Fig. 7 Analytical Vs MATLAB Results for Configuration -3

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Configuration 4:

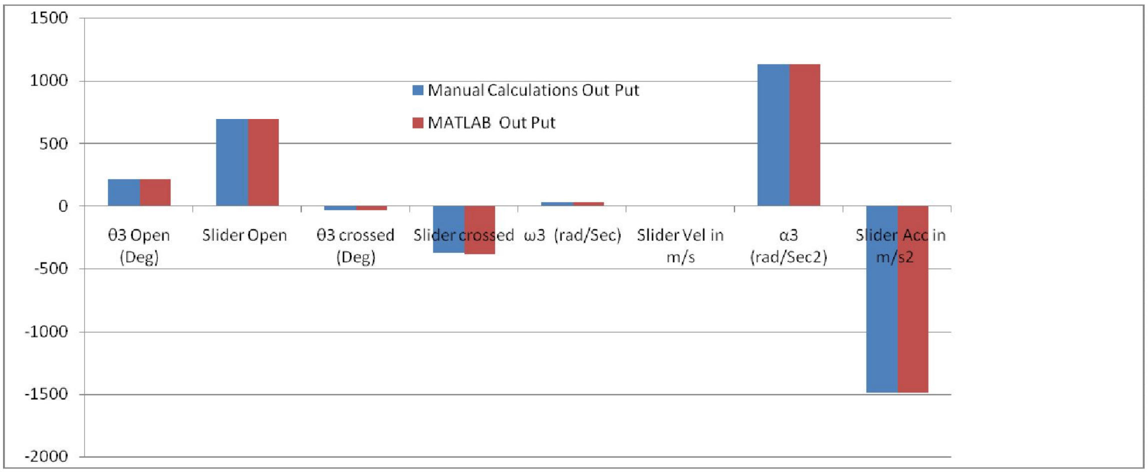

Fig. 8 Analytical Vs MATLAB Results for Configuration -4

IV. Conclusions

In this Project an attempt has been made to study on four bar Slider Crank Mechanism by CATIA and MATLAB Softwares. By using MATLAB Software we can simulate and calculate the remaining link positions (Coupler and Slider). In this project the MATLAB code gives the all calculations as an excel file as output and it generates an animation in 2D Plot. DMU Kinematics Simulator provides users the ability to define a point in a moving part and generate it trace for the mechanisms. During mock-up design review, users do not only need to view simulated kinematics but also analyze the mechanism's consistency with the functional specifications. DMU Kinematics Simulator performs interference and clearance checking as well as computing the minimum distance. A 'stop on collision' option freezes the motion for detailed analysis. The Softwares CATIA and MATLAB are very fast and less laborious and very efficient than graphical methods.

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