# Dynamic Analysis and Simulation of a Horizontal Slider Crank Mechanism using Spreadsheets

*Yasser A. Nogoud[1], Sakhr Abudarag[1], Shuhaimi Mansor[2], Attie Jonker[3]*

[1]Department of Aeronautical Engineering, Sudan University of Science and Technology (SUST), Sudan
[2]Department of Aeronautical, University Technology Malaysia (UTM), Malaysia,
[3]School of Mechanical Engineering, North-West University, South Africa

*Received on: 29/10/2017*
*Accepted on: 11/01/2018*

***ABSTRACT*** - This paper proposes a spreadsheet method for modeling, simulation and analyzes a mechanism of a horizontal, single cylinder, four-stroke internal combustion engine. The method is based on the use of analytical approach because it is more accurate, moreover is less time consuming if it is programmed for the computer solution. The spreadsheet model is a parametric model and it gives a simple visual presentation of the mechanism with interactive movement and control by the user. This method can be used for kinematic and dynamic analysis with the ability to make quick and easy parametric changes to a design. Compared with professional simulating software and advanced program language, the way proposed in the paper is convenient and practical.

***Keywords:*** *Excel; crank slider mechanism, kinematics analysis, modeling.*

**المستخلص**– تقدم هذه الورقة طريقة لنمذجة ومحاكاة وتحليل آلية لمحرك الاحتراق الداخلي الأفقي، المكون من اسطوانة واحدة، ذات اربعة اشواط باستخدام طريقة جداول البيانات. وتستند العملية على استخدام النهج التحليلي لأنه أكثر دقة من الطرق الأخرى، علاوة على ذلك تستغرق هذه الطريقة زمن اقل لاستخراج النتائج إذا ما تمت برمجتها للحل بواسطة الكمبيوتر. نموذج جدول البيانات هو نموذج بارامتري، ويعطي عرضا مرئيا بسيطا للآلية مع حركة تفاعلية ويمكن التحكم بها من قبل المستخدم. يمكن استخدام هذه الطريقة لتحليل حركي وديناميكي مع القدرة على إجراء تغييرات بارامترية سريعة وسهلة. مقارنة مع برامج محاكاة احترافية ولغات البرمجة المتقدمة، تعتبر الطريقة المقترحة في هذه الورقة طريقة عملية و مريحة.

## *INTRODUCTION*

The internal combustion engine employs a very popular mechanism known as slider crank mechanism. The mechanical control system of a slider crank can be described as a kinematical chain. This is defined as assemblage of links and joints interconnected in a way to provide a controlled output motion in response to a supplied input motion [1]. Due to the interaction of the various elements in the kinematical chain and the difficulty in visualizing the movements it can be very difficult to design and optimize such a system. Some modern Computer-Aided Design (CAD) systems offer users the option of simulating movements and to check for geometric anomalies [2, 3]. These software packages are normally very expensive and beyond the reach of a small or new company. Although with the programming language of Visual C/C++, Fortran and Matlab can exert optimization design, its complexity in programming and difficulty in dynamic simulation makes hard to master for most engineers [4-9].

This problem can however be easily solved by the use of a spreadsheet. Almost all standard desktop word processing bundles include a spreadsheet program. It is possible to use a spreadsheet to model the kinematics of a complete horizontal slider crank for a single-cylinder four stroke internal combustion engine. The results are interactively available via the mouse in a graphical format. This allows one the freedom to investigate the influence of changes on the system and to optimize the system quickly and easily.

Kinematic analysis of the slider-crank mechanism helps to answer many questions pertaining to the motions of various links of the mechanism vs. displacement, velocity and accelerations of driven members like connecting rod and piston. In the present work, the complete kinematic analysis of the engine has been carried out by analytical method using complex-algebra method as this method is more accurate than graphical method and can give results for all the phases of the mechanism.

## *CRANK SLIDER MODELING*

A slider crank mechanism can be broken down into three basic elements. These are a crank shaft element, a connecting rod element and a slider element. A crank shaft is considered as a rigid rod with pinned joints at the ends and a single rotational point about which it can pivot. The basic parameters for the arm element are the arm length and the angle between arm and horizontal. The coordinates of the end and the pivot point define the position of the arm. The rotational position of the arm is defined as the angle between arm and the horizontal.

A connecting rod element is considered as a single rigid rod with pinned joints at each end. The basic parameter is the length of the link while the coordinates of the end points define the position. The rotational position is defined as the angle between the link and the vertical.

A slider element is any element in which the one end of a link can slide along a prescribed path. The basic parameter is the length of the linear displacement of the slider while the coordinates of the end points define the position. Figure. 1 shows the definition of these elements with the basic parameters associated with each element.

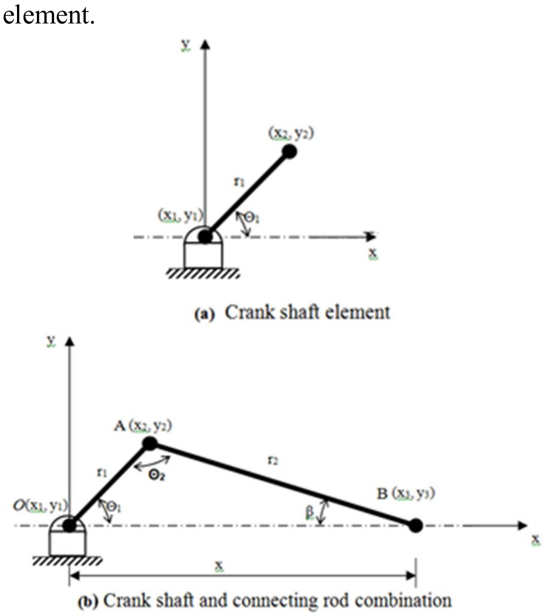


**Figure1: (a) kinematic sketch of crank shaft and (b)crank shaft and connecting rod combination**

When combining the basic elements to form a kinematical chain, the problem is finding the position of each of the elements based on the input values and the geometrical constrains of the system. The geometrical constrains are the system parameters like link and arm lengths, and pivot positions.

The most basic system in this paper is a crank shaft length with a specific pivot position (Figure.1 a). This then defines the position and the rotational angle of the crank shaft. If the pivot position ($x_1$,$y_1$) and the length of crank shaft ($r_1$) are known the rotational angle ($\theta_1$) and the position ($x_2$,$y_2$) of the output crank shaft are simply:

$$\theta_1 = tan^{-1}\left[\frac{y_2 - y_1}{x_2 - x_1}\right] \quad (1)$$

$$x_2 = x_1 + r_1 \cos\theta_1 \quad (2)$$

$$y_2 = y_1 + r_1 \sin\theta_1 \quad (3)$$

Figurer. 1(b) shows a connecting rod coupled to a crank shaft. Line AB represents the connecting rod with length $r_2$ while OA represents the crank shaft with length $r_1$ and the pivot point O ($x_1$,$y_1$). The coordinates of O and A are known and the object is to find the coordinates of B. This can be obtained by calculating the intercept point of the circles with origin B, radius $r_2$ and origin O, radius $r_1$. This approach is however difficult to implement on a spreadsheet so that a direct geometrical solution was derived as follows:

$$x = r_1 \cos\theta_1 + r_2\sqrt{1-\left(\frac{r_1}{r_2}\right)^2 \sin\theta_1^2} \quad (4)$$

$$\theta_2 = cos^{-1}\left[\left(\frac{x^2-r_1^2-r_2^2}{-2r_1r_2}\right)\right] \quad (5)$$

$$\beta = \sin^{-1}\left[\frac{r_1 \sin\theta_2}{x}\right] \quad (6)$$

Now it is possible to simulate a complete system of crank shaft, connecting rod and slider piston together. This will be shown in the following section.

## *DYNAMIC SIMULATION*

Figurer. 2 shows a typical horizontal, single – cylinder, four stroke internal combustion engine, consisting of crank shaft, connecting rod and piston.

Figure 3 shows the spreadsheet model. There are calculation boxes for each element. All the geometrical data is filled in for every element after which the couplings can be performed. The couplings are shown as arrows. The couplings must be performed by hand, but it is very simple and quick. The output result is the graphical representation in the right-hand corner. The input to the simulation is a mouse-controlled scrollbar. The values of the scrollbar can be set and is linked to the rotational angle of the crankshaft.

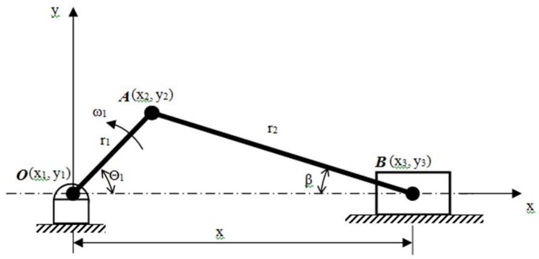


**Figure.2: Kinematic sketch of slider crank mechanism**

The simulation provides a real-time graphical simulation result, which proves to be very useful in the design of control systems. The parametric nature of the spreadsheet element models allows quick changes to the geometry and the ability to view the results immediately. This simplifies the optimization of the system greatly.

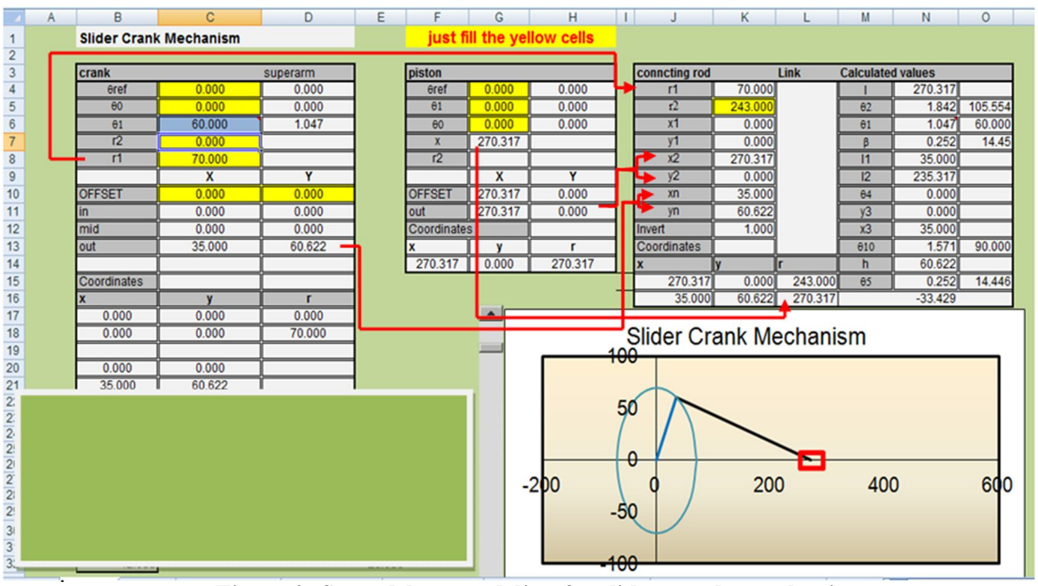


**Figure.3: Spreadsheet modeling for slider cranks mechanism.**

***KINEMATIC ANALYSIS***

It is also possible to use this model to calculate the kinematic parameters of each member. This can be done by realizing that the kinematic parameters in the crankshaft and connecting rod is the angular velocity, angular acceleration, while in the slider piston is the linear velocity and acceleration and linear displacement. All the geometry data at a specific instance is available in the model and the rotational speed of the crankshaft is constant (1800 rpm) so that the kinematic parameters for each member can be calculated. As shown by the following equation [10]

$$V_p = \omega_1 r_1 \left( \sin\theta_1 + \frac{\sin 2\theta_1}{2 * {r_2}/{r_1}} \right) \quad (7)$$

$$a_p = \omega_1^2 r_1 \left( \cos\theta_1 + \frac{\cos 2\theta_1}{2 * {r_2}/{r_1}} \right) \quad (8)$$

$$\omega_2 = \frac{[\omega_1 \cos\theta_1]}{\sqrt{\left[\left({r_2}/{r_1}\right)^2 - \sin\theta_1^2\right]}} \quad (9)$$

$$\alpha = \frac{[-\omega_1 \sin\theta_1]\left[\left({r_2}/{r_1}\right)^2 - 1\right]}{\left[\left({r_2}/{r_1}\right)^2 - \sin\theta_1^2\right]^{3/2}} \quad (10)$$

where, x: Displacement of piston, $v_p$:Velocity of the piston,$a_p$:Acceleration of the piston,$\omega_2$:Angular velocity of the connecting rod, a: Angular acceleration of the connecting rod, $\theta_2$:Angle between crank and connecting rod, and$\omega_1$:Crank speed.

A kinematic calculation cell was added to the model. The kinematic parameters in each component are now directly available as a function of the position of the crankshaft as shows in Figurer4, Figurer 5 and Figurer 6.

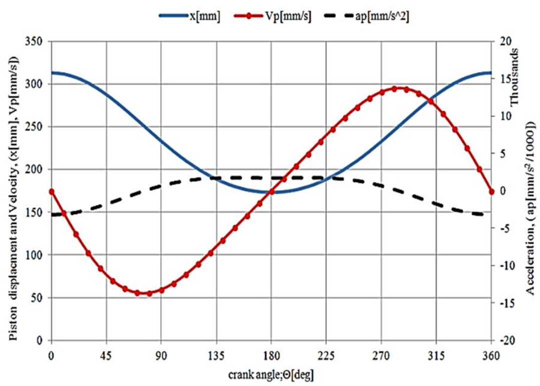


**Figure 4: piston position, velocity and acceleration Vs. Crankshaft rotational angle**

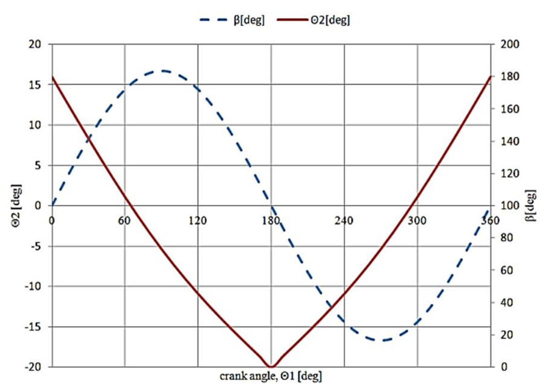


**Figure 5: connecting rod angle and angle between crankshaft and connecting rod Vs. Crankshaft rotational angle**

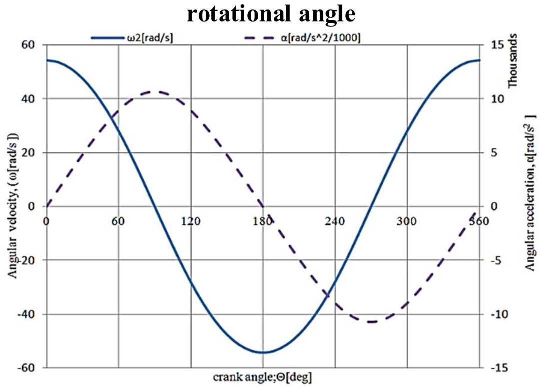


**Figure 6: Angular velocity and Angular acceleration Vs. Crank rotational angle**

***CONCLUSION***

A parametric spreadsheet modelling method for horizontal crank-slider mechanisms was developed. This modelling method allows the use of Excel to model crank-slider mechanisms as found in the horizontal, single – cylinder, four-stroke internal combustion engine. This method allows real-time simulation of control kinematics with the ability to make quick and easy parametric changes to a design. It also has the ability to calculate the loads imposed on each component in the control system as a function of input loads and position. The programme can simulate and analyse various types of linkages such as four and five links mechanisms. Finally, it can be used as an educational program for undergraduates' students in mechanical engineering.

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