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A Computer Simulation of a Modified Oldham Coupling

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ABSTRACT

In this research, an Oldham coupling is used, and it has been modified to obtain new features. The modification is made on the intermediate part of the Oldham coupling and hence a kinematic model is approached, and two new applications are found. The proposed mechanism can be used as a function generator for some specific functions such as cardioid for the ratio, crank/shift=1, and the second finding as a sort of quick return mechanism. The results of the mathematical model show a good agreement with those of the cad model simulation and the related literature.

Keywords:

Oldham , coupling , quick return mechanism , simulation , function generator.

1. INTRODUCTION

Most mechanical systems have one or more coupling devices among their components. Basically, the classical Oldham coupling, named after the Irish engineer John Oldham [1], contains three parts, the first part which is connected to the driving shaft, the second part which is connected to the driven shaft and usually similar to the first part and the third intermediate (floating) part, which connects part (1) to part (2). Those three parts are engaged together by linear and perpendicular slots as shown in Fig.1.

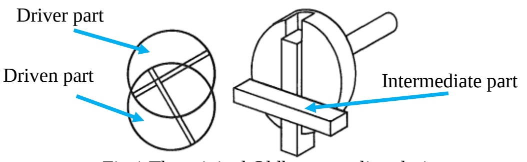

Fig.1 The original Oldham coupling design

The purpose of the slots in Fig 1 is for motion transmission from the driver to the driven as well as allowing for any relatively expected misalignment between them. Ferguson presented a practical version of the Oldham coupling [2], Fig 2. Freudenstein introduced the generalized Oldham coupling using circular or curvilinear slots[3], Fig 3, which is considered a modified version of the one presented by ….. [1]. The output speed of the coupling is found to be non – uniform while it is uniform for the classical Oldham coupling where linear slots are used.

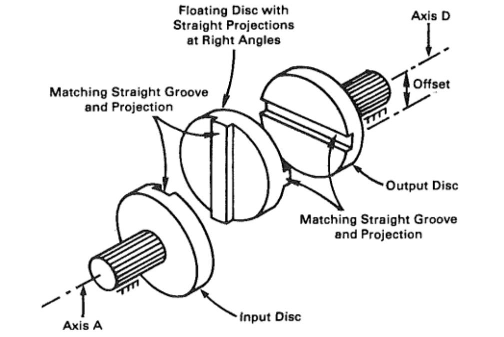

Fig.2 Practical Version of the Oldham Coupling

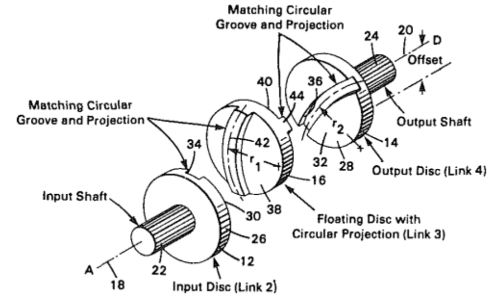

Fig.3 Generalized Oldham Coupling

Furthermore, Freudenstein found an application for this setup as a periodic phase change between the input and the output shafts and suggested to be used as a quick return mechanism. Tsai used two generalized Oldham coupling as second – harmonic balancer[4].

[5] ……. introduced a modern quick return mechanism using the suggested generalized

Oldham coupling of Freudenstein, Fig.4.Reference [5] will be used here for comparison purposes with the current research.

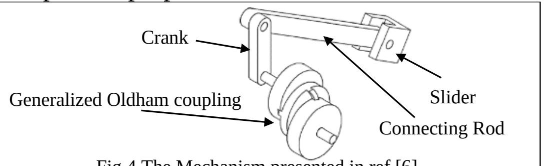

Fig 4 The Mechanism presented in ref [6]

2. TARGET OF THE RESEARCH

The goal of this study is to present a modified setup of the Oldham coupling version of Reuleaux, via changing the geometry of the intermediate part only, leading to produce a new mechanism of different objectives.

3. GEOMTRY OF THE SUGGESTED MECHANISM

The driving and driven parts geometry of the Oldham coupling are kept unchanged, the modification is made only on the intermediate part by splitting it into two similar pieces and then re-assembled via a relatively small shaft producing a crank as shown in Fig 5 - a in such a way that each slot is perpendicular to each other exactly like those before the splitting process. The crank is then connected to a piston by a connecting rod giving a setup similar to the famous slider – crank mechanism, Fig 5 - b. An intentional misalignment is made on the mechanism in both directions, x and y, Figures 5 – c and 5 – d, respectively.

4. POSITION ANALYSIS OF THE MECHANISM

The proposed mechanism was analyzed kinematically to study the effects of the modified part on the motion of the piston as well as the intermediate part itself. The movement of the intermediate part, the blue-red, is ruled by the motion of the driver part, the orange, as well as the driven part, the yellow, hence the motion analysis must include both parts in addition to the blue-red.

Figure 6 shows the analysis of the present suggested mechanism. Point o, the center of the driver, the orange part, is chosen to be the origin, point o' represents the center of the driven part, the yellow part, is shifted away from the origin by s_x unit length, which represents the amount of the shift (misalignment) in the x – direction and s_y, the amount of the shift in the y – direction. $\overline{oo'}$ represents the total shift, 2b, in the xy plane. Point k represents the center of the crank that lies on the intermediate part, which also represents a point to be traced for the predicted trajectory, $\bar{r} = \overline{ke}$ represents the radius of the crank, e represents the center point of the intermediate part, θ represents the angular displacement of the driver. α, the phase angle, is the angle measured from the positive x' – axis of the left component of the intermediate part, the

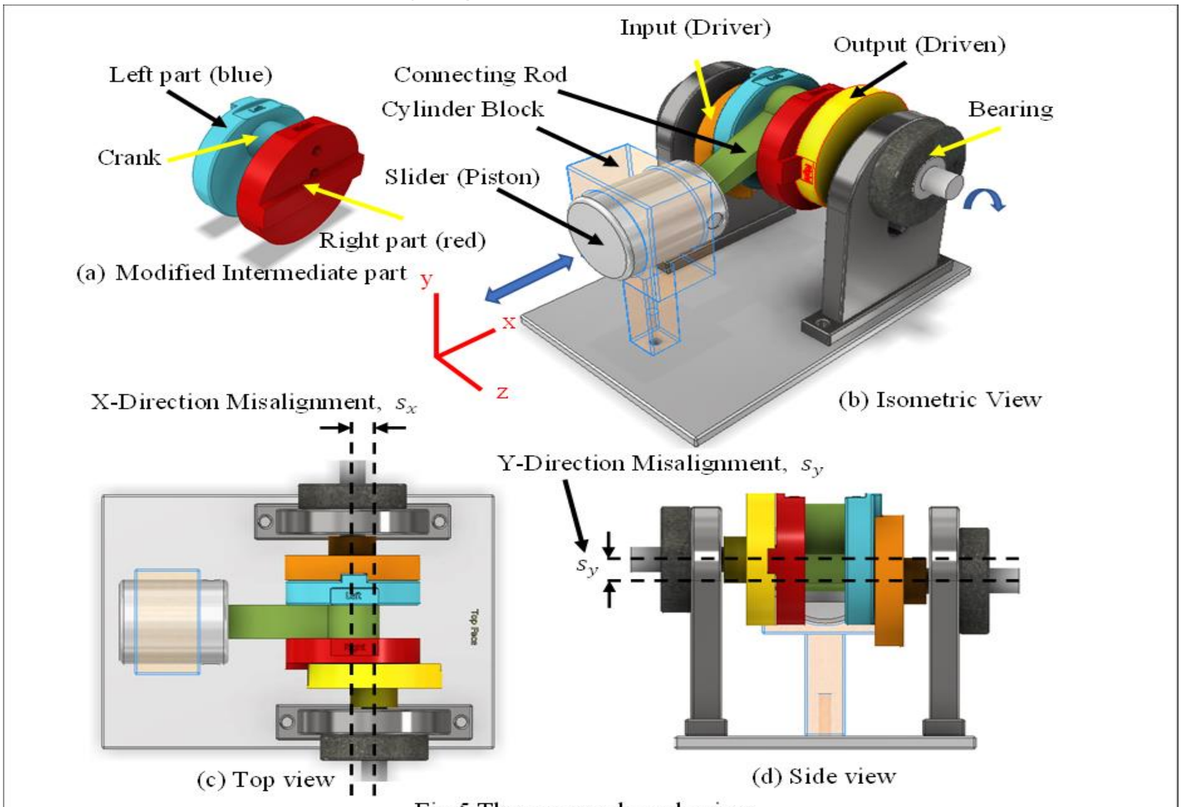

Fig 5 The proposed mechanism

blue, and it determines the angular position of the crank relative to a slot that is parallel to the x' – axis . Vectors $\overline{co}$, $\overline{ec}$, and $\overline{o'c}$ all have the same magnitude because points (e,o and o') lie on a *virtual* circle whose center is c because $\overline{o'e}$ is always perpendicular to $\overline{oe}$, which are indeed the two perpendicular slots of the intermediate, blue-red, part. Point p is the slider (piston) and $\overline{kp}$ represents the connecting rod. Vector algebra shows that the position of points k and p with respect to the origin, o, for any angle θ can be found as follows:

$\overline{ko} = k_x \bar{\imath} + k_y \bar{\jmath} = \overline{co} + \overline{ec} + \overline{ke}$,

Hence, the above equation will be as follows:

$k_x = x(\theta) = \frac{s_x}{2} + b\cos(2\theta - \beta) + r\cos(\alpha + \theta)$ …….. (1)

$k_y = y(\theta) = \frac{s_y}{2} + b\sin(2\theta - \beta) + r\sin(\alpha + \theta)$ ……. (2)

And from geometry :

$b = \frac{\sqrt{{s_x}^2 + {s_y}^2}}{2}$, $\beta = \tan^{-1}\left(\frac{s_y}{s_x}\right)$, and $\omega = 2(\theta - \beta)$ …….. (3)

$\overline{po} = p_x \bar{\imath} + p_y \bar{\jmath} = \left(-\left|\overline{kp}\right| \cos\phi + k_x\right)\bar{\imath} + p_y \bar{\jmath} = \left(k_x - \left|\overline{kp}\right| \cos\left(90 - \cos^{-1}\frac{k_y - P_y}{\left|\overline{kp}\right|}\right)\right)\bar{\imath} + p_y \bar{\jmath}$ ………… (4)

Where ω is the angular movement of the intermediate part.

Note: The only x – component of the slider, p, is taken here because the piston is assumed to slide horizontally along the x – axis at $y = 0$.

5.VALIDITY OF THE MODEL

The derived model has been validated by two methods. The first method depends on predictions for three different cases. It is also validated by using a simulation software as a second but a main method of a scientific comparison in addition to the available literature.

5.1 THE PREDICTIN METHOD

5.1.1 THE NO SHIFT CASE

The trajectory of the point k when ($s_x = s_y = 0$) and for any value of the radius (r) and the angle (α), is purely circular profile around the origin and it is an intuitive result because it represents the situation when there is no misalignment between the driver and the driven parts, and can mathematically be verified by using equations (1) and (2) which will lead to an equation of a circle of radius (r) and the coordinate (0,0) to be its center point. The stroke of the slider will be exactly $2r$ if $P_y = 0$.

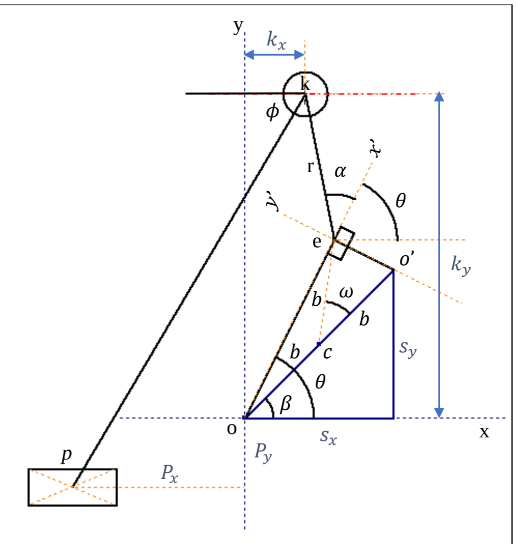

Fig 6 Geometry of the Mechanism

5.1.2 THE NO CRANK CASE

For any value of shift (s_x and/or s_y) and the angle (α), and for ($r = 0$), the trajectory will also give a circular profile while its center lies away from the origin by a distance equal to the half of the total shift.Point k will lie on point e. This result is obvious by observing that point (e) will follow a circular path around the center point (c). A mathematical proof can be made by using equations (1) and (2), which will produce a circle with a center point lying at a position that depends on the shift values. For example, when ($s_x = a, s_y = 0$), the coordinate of the center c will lie at $\left(\frac{a}{2}, 0\right)$ and the stroke is exactly equal to $s_x$if $P_y = 0$. Also, equation (3) shows that $\omega = 2(\theta - \beta)$ where ω represents the angular displacement of the intermediate part. Hence, it will turn two revolutions per each revolution of the driver [2].

5.1.3 THE NO CRANK AND NO SHIFT CASE

This case gives only one point as a trajectory profile that lies at (0,0) and this result can be obtained by using equations (1) and (2). Once again, this result is intuitive and predictive. In fact, this case represents the case of using a classical Oldham coupling when there is no misalignment between the driver and the driven parts and therefore the slider will make no displacement due to zero crank value.

5.2 THE SIMULATION METHOD

The proposed mechanism has been simulated by using cad software, Fig 7. Simulation software started to be used in the last decades for kinematic analyses and proved their reliability for being employed as an efficient comparing tool [6]. The results of the simulation were in a very good agreement with those of the model as well as between the case study, section 8.0.

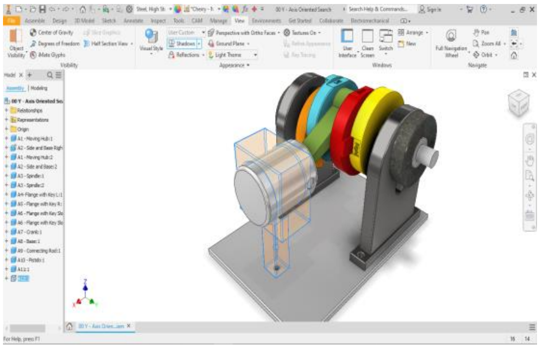

Fig 7 The proposed mechanism modeled and simulated using cad software

6. RESULTS AND DISCUSSIONS

6.1 EFFECT OF THE CRANK RADIUS TO SHIFT RATIO

The ratio of the crank radius to the total shift is found to be a suitable dimensionless parameter for this study. It has been shown that this ratio has a significant effect on the mechanism. The angle α is kept constant, during the following four cases, at $\propto = 0^{o}$, and the shifts were set at $s_x = 10$ unit length and $s_y = 10$ unit length. All the following figures represent the trajectory of the point k, appeared earlier in Fig 6 in the xy plane, for a complete revolution of the driver.

6.1.1 CASE I ($CRANK/SHIFT = 0$)

In this case, a circle was obtained of diameter equals to the shift, 2b, and its center lies at the middle of the line connecting the origin of the driver part, o, and the origin of the driven part, o', as shown in Fig 8 for both model, eq(1) and eq(2), and simulation. Furthermore, this case proves section 5.1.2.

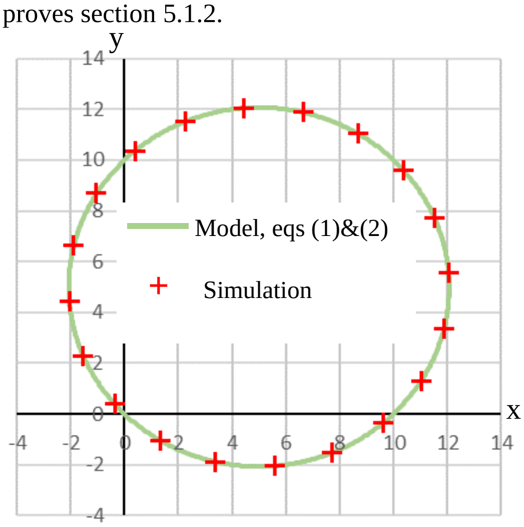

Fig 8 Effects of $({}^{r}/_{2b} = 0)$ on the Mechanism.

6.1.2 CASE II ($0 < CRANK/SHIFT < 1$)

This case gave the trajectory that is shown in Fig 9 for $r/2b = 0.5$. Here we got what is mathematically called Limacon with inner loop, [7] and [8]. The size of the inner loop will approach the size of the outer loop as that ratio approaches zero which will lead exactly to the previous case. Hence, the blue-red part, i.e., the intermediate part, will make two revolutions (major and minor loops) per each revolution of the input driver and hence may be used as a mechanism for doubling the speed of the slider without using gears or belts and this result is in a good agreement with [2]. Long stroke and short stroke per each revolution of the driver will be obtained for this study range and they will be the samefor the case of $(crank\ /\ shift = 0)$.

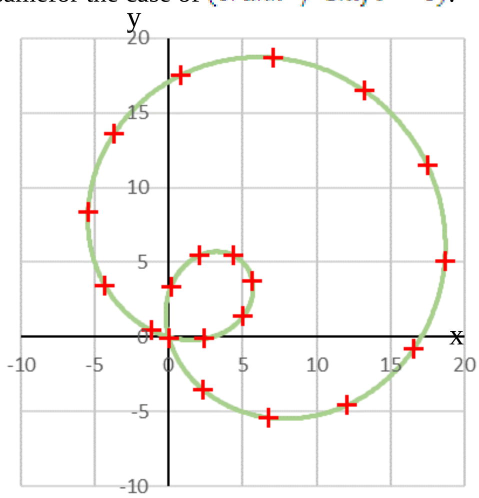

Fig 9 Effects of $({}^{r}/_{2b} = 0.5)$ on the Mechanism.

6.1.3 CASE III ($CRANK/SHIFT = 1$)

A mathematically called Cardioid, (heart – shaped), curve is obtained in this case withoutinner loop. Fig 10, [7] and [8].

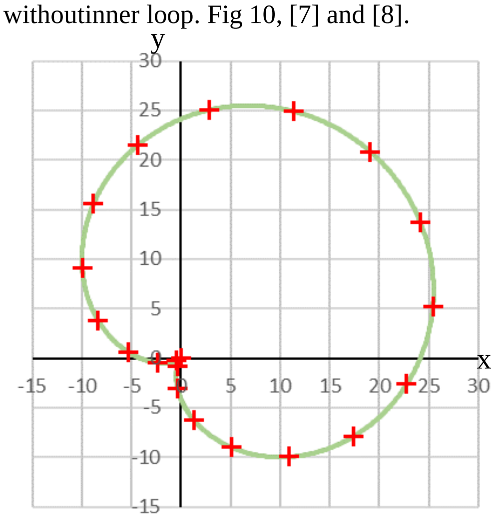

Fig 10 Effects of $({}^{r}/_{2b} = 1)$ on the Mechanism.

6.1.4 CASE IV ($CRANK/SHIFT > 1$)

The trajectory in this case is called dimpled Limacon, when ($1 < r/2b < 2$) and convex Limacon when ($r/2b \geq 2$), [7] and [8]. Fig 11 shows this case for $r\ /\ 2b = 1.5$. As this ratio becomes larger and larger the trajectory becomes a semi – circular profile because the first and second terms of equations (1) and (2) will be neglected compared to the third term, respectively.

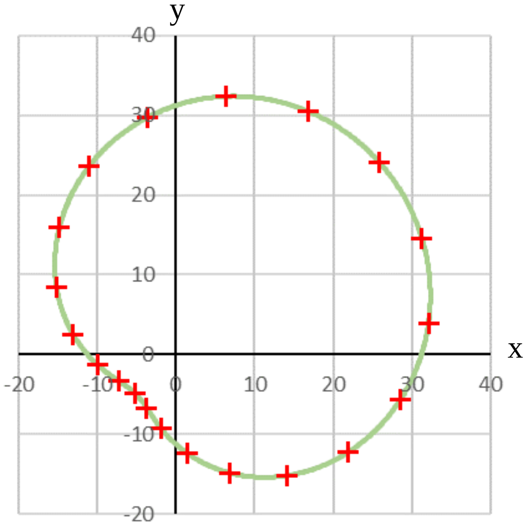

Fig 11 Effects of ($^{r}/_{2b} = 1.5$) on the Mechanism.

6.2 EFFECTS OF THE PHASE ANGLE (α)

The effects of changing the phase angle, α, are shown in Fig 12. All other parameters are kept unchanged as follow, $s_x = 10$ units, $s_y = 10$ units and $r/2b = 0.7$. This figure shows that changing this angle will consequently change the location of the inner loop and this behavior may have some advantages in the case of designing certain mechanisms, for instance, a quick return mechanism. Because changing the inner loop position will decide its type, it will be (quick or slow) return mechanism if we choose the case represented by Fig 12-b. And it will be only almost return mechanism like the slider – crank mechanism if we choose the setup represented by Fig 12-d,

where the time for the forward stroke is approximately the same as that of the backward stroke. Knowing that the latter case can also be obtained if we made no shifts in both axes and took relatively any crank radius. To reduce the effect of the inner loop, one can choose greater value for the crank to shift ratio as depicted in Fig 11.

7. PROPSING THE CURRENT MECHANISM AS A QUICK RETURN MECHANISM

The shape of the trajectory of point k, as shown in previous Figures (8-11 and 12), gave the mechanism a potential ability to be used as a quick return mechanism. Any quick return mechanism has what is so called time ratio, *TR*, which is the time elapsed for the advance (forward) stroke, t_A, divided by the time elapsed for the return (backward) stroke, t_R, [9], [10] and [11], or:

$$TR = \frac{t_A}{t_R} \ \ldots\ldots\ldots\ldots\ldots \ (5)$$

Figures (13-18) show the effects of the crank radius to the shift ratio on the forward and backward motions of the slider (piston) for a complete cycle during 1 second of time by using equation (4).

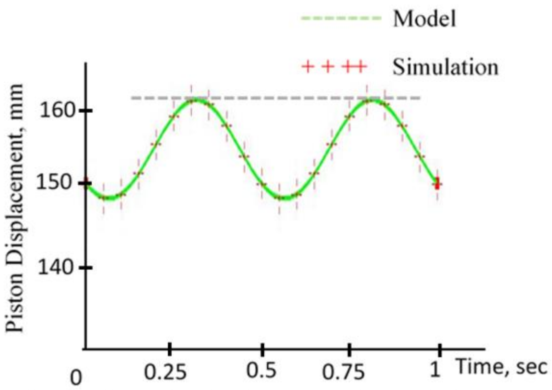

Fig.13 Effect of (r/2b=0.0) on the piston displacement

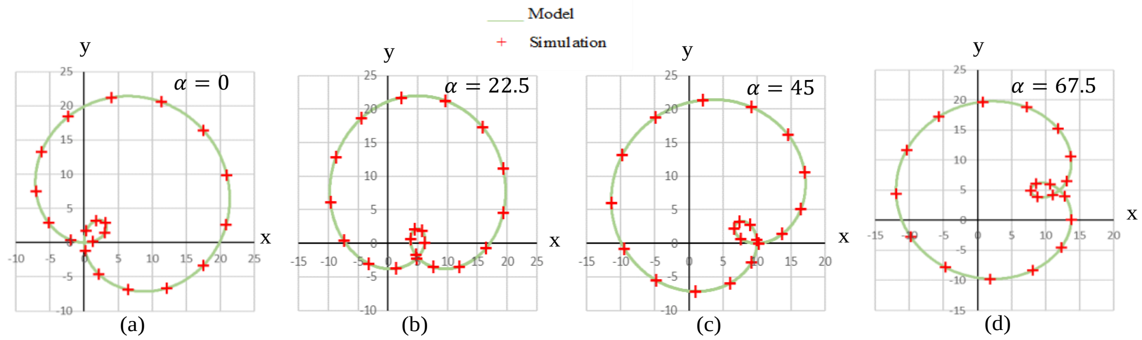

Fig 12 Effects of the phase angle α on the Mechanism.

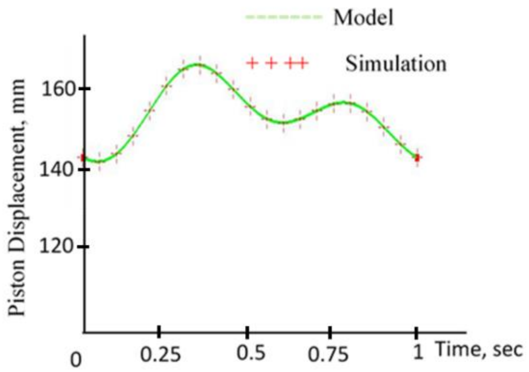

Fig.14 Effect of (r/2b=0.5) on the piston displacement

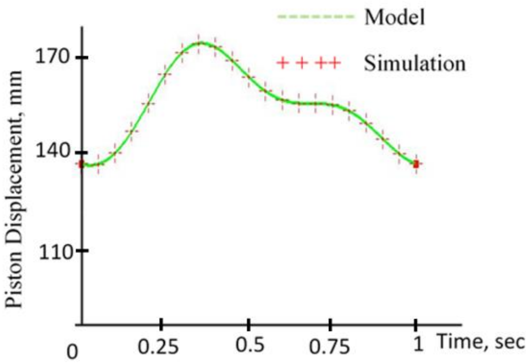

Fig.15 Effect of (r/2b=1.0) on the piston displacement

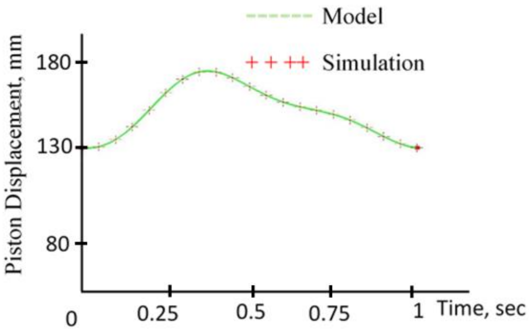

Fig.16 Effect of (r/2b=1.5) on the piston displacement

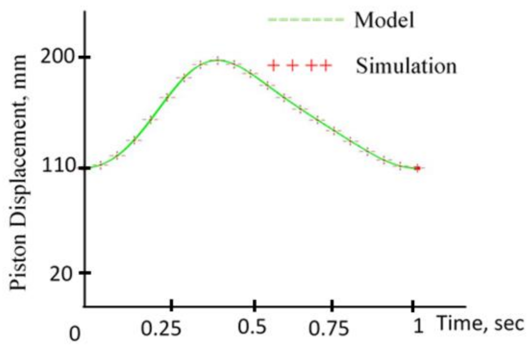

Fig.17 Effect of (r/2b=3.0) on the piston displacement

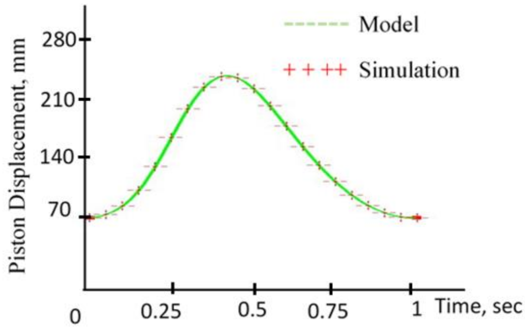

Fig.18 Effect of (r/2b=6.0) on the piston displacement

8.0 CASE STUDY

Table 1 shows the parameters used in the current model which are adopted here for comparison purposes with [5]. The results are shown in table 2 and Fig 19, respectively.

Table 1: Parameters used in the present model and reference [5]

No.	Parameters	Value (mm)
1	Shift in the x – direction, s_x	13.29
2	Shift in the y – direction, s_y	0
3	Crank radius, r	50
4	Connecting Rod	175
5	Vertical distance between the slider and the origin, p_y	-37.5

Table 2: Comparison between the results of the present model and [5]

No.	Parameter	Present Model	Ref [5]	Units	Error (%)
1	Time Ratio	1.75	1.65	Dimensionless	~6.1
2	Stroke	102.4	102.61	mm	~0.2

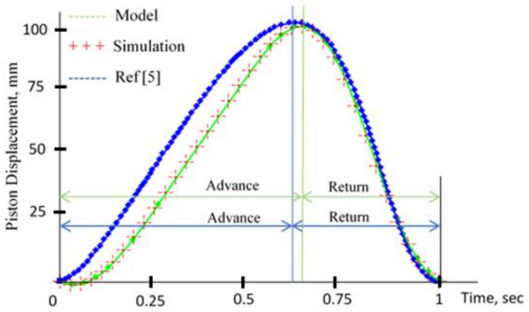

Fig.19 Comparison between the model, eq (4) and Wen-Hsiang et al [5]

The difference in time ratios between the two studies can be considered advantageous because the more the slider returns quickly the more the mechanism to be accepted. The difference in stroke ratios seems to be very small and can be ignored. In general, Table 2 and Fig 19 show a good matching between the present study and [5].

Finally, Fig 20 represents different crank radii to the total shift ratios all plotted in one graph. See attached video for more demonstration. The curves from inside out have the values ($r/2b$= 0.5, 1.0, 1.5, 2.0 and 2.5, respectively). The phase angle, α, is kept constant at $-22.5^o$and $s_x = s_y = 10$units length. The solid lines are for the model, equation (1) and (2), and the dots are for the simulation.

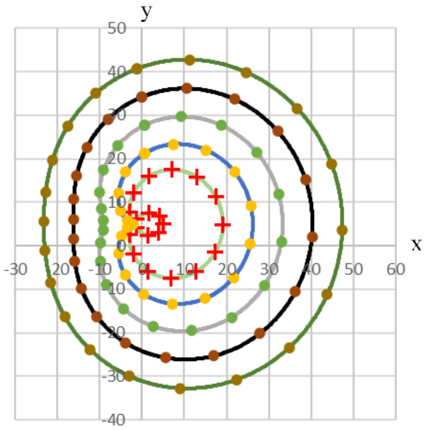

Fig 20 Effects of different values of ($^r/_{2b}$) on the Mechanism.

9. CONCLUSION

The conclusions may be summarized as follows:

1- Case I,$^r/_{2b} = 0$, section 6.1.1, is similar to the case of crank and piston mechanism in which the stroke depends completely on the crank radius.The advance to return strokes ratio equals one. Furthermore, two strokes per each revolution of the input is observed. It is a speed doubling device for the slider.

2- The present mechanism can be used in mathematics and industry as a mechanical device for drawing or machining cardioid$^r/_{2b} = 1$,or Limacon shapes$0 < {}^r/_{2b} < 1$, cases II – VI. Hence, it is a function generating mechanism.

3- Any point on the intermediate part of the coupling can produce any of the previous mentioned shapes, Fig 8 – Fig 12, of different sizes depending on the crank radius to the shift ratio, $^r/_{2b}$, and the angle α. Excluding point, c, which will always produce circles except for the case of no misalignment, i.e. no shift, section 5.1.1.

4- Referring to Fig 19, the suggested mechanism can be recommended to be used as a quick return mechanism.

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محاكاة حاسوبية لقارنة اولدهام مطورة

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الملخص

تم استخدام قارنة اولدهام في البحث الحالي بعد ان اجري عليها تطويرا ميكانيكيا لغرض الحصول على ميزات جديدة، لقد اجري التطوير على الجزء المتوسط من القارنة. ولقد تم التوصل الى نموذج رياضي حركي مما ادى الى الحصول على تطبيقين للنموذج المقترح. احد تلك التطبيقات هو امكانية استخدام النموذج الحالي كمولد رياضي لبعض الدوال كالدالة التي تشبه القلب عند النسبة 1. اما التطبيق الثاني فهو امكانية استخدامه كالية رجوع سريعة. لقد تمت محاكاة النموذج بأستخدام الحاسوب مما ادى الى حصول على نتائج متوافقة بشكل جيد مع نتائج النموذج الرياضي وكذلك مع البحوث السابقة.

الكلمات الدالة :

اولدهام، قارنة، الية رجوع سريعة، محاكاة، مولد دوال