

## Theoretical Study and Computer Simulation of a Modified Quick Return Mechanism

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### Abstract

Quick return mechanism, (QRM), is considered one of the important mechanisms. It is always desired to increase machine productivity and/or to decrease time losses. Shapers, for instance, have a considerable importance in production engineering, they have gearboxes for speed variation purposes required for cutting, and most of them employ QRM. This study aimed to introduce coupling with a pre – determined misalignment engaged to QRM in order to obtain an enhanced QRM that has different time ratios and speed ratios. This modification then applied to shaper for making precise speed adjustment of the cutting and return speeds of the ram beside the gearbox. Consequently, the resulted high time ratios ( $TR > 1$ ) enhanced the productivity of the shapers for the same ram stroke. The lower return time the higher the productivity. Furthermore, the “quick” effect of the QRM retained even with shorter strokes by the present modification. The research tools included mechanism modeling and simulation using Autodesk Inventor Professional Software. In addition, it includes theoretical velocity analysis for the resulting combination. Both simulation and theoretical analyses agreed well.

Key words: Quick return mechanism, shapers, parallel misalignment, time ratio.

### دراسة نظرية ومحاكاة حاسوبية لآلية رجوع سريع مطورة

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### الخلاصة

تعتبر آلية الرجوع السريع من الميكانيكيات المهمة. ومن المعلوم إن زيادة إنتاج ماكينة ما هو من الأمور المرغوبة جدا وذلك من خلال زيادة سرعة الماكينة مثلا أو التقليل من خسائر الزمن. فالمقشطة مثلا تعتبر ذات أهمية كبيرة في مجال هندسة الإنتاج وتحتوي على صندوق سرعة لأغراض تغيير سرعات القطع وان معظمها يعمل بالية الرجوع السريع. إن الهدف من البحث الحالي هو تقديم آلية رجوع سريع مطورة ذات نسب زمن ونسب سرعة مختلفة. ولقد طبقت هذه الآلية على المقشطة لأجل التحكم الدقيق بسرعة القطع وسرعة رجوع تمساح المقشطة (ram) فضلا عن صندوق السرعة. وكنتيجة لذلك ساهمت نسب الزمن العالية التي حصل عليها في تحسين إنتاجية الماكينة إذ انه كلما قل زمن الرجوع زادت إنتاجية المقشطة. وكذلك بين البحث إمكانية احتفاظ آلية الرجوع السريع بخاصية "الرجوع السريع" والواضح حتى مع الأشواط القصيرة جدا بسبب استخدام التحسين الحالي. تضمنت أدوات البحث استخدام برنامج الـ Autodesk Inventor Professional لنمذجة ومحاكاة الآلية الحالية فضلا عن تحليل السرعة نظريا. ولقد تطابقت نتائج المحاكاة تطابقا جيدا مع النتائج النظرية.

الكلمات المفتاحية: آلية الرجوع السريع, المقاشط, عدم محاذاة من النوع الموازي, نسبة الزمن.

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## 1.0 Introduction

The limited cutting speed and the time lost during the reverse stroke are the main reasons behind the low productivity of shaping machines [1]. The variety of materials in production requires manufacturing machines that should have various options, and hence, speed variation is one of those basic options. For instance, if a steel workpiece is required to be machined using shaper then the speed of cutting must be suitable otherwise the cutting process may fail due to high impact load and excessive heat generation because of the high speed of cutting. In the other hand, it would not be productive as well as bad surface finish will be obtained if low speed of cutting is used [2]. Furthermore, if the length of workpiece is small it means that the ram stroke of the shaper will also be small then the quick return mechanism will have approximately the same speed for both the cut and return strokes and the same time for both strokes as shall be seen and cured in later. For such case, another mechanism or modification which is capable of maintaining quick return mechanism again even with very small strokes is required, as well as capable of changing the speed accurately.

Shaft misalignment, which occurs when the centerlines of rotation of two machinery shafts are not in line with each other [3], may be used for speed variation purposes. Misalignment considers a main problem for field engineers who often suffer when they try to fit components to their right positions, which, in turns, occupies their attention. However, and among all its demerits, misalignment may have an advantageous usage, which will be investigated throughout this research. There are three types of shaft misalignment [3] [4]: parallel, angular and mixed misalignment as shown in figure (1) below.

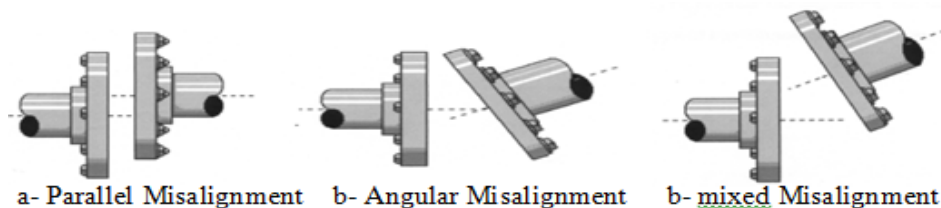


Figure (1) Types of misalignment

Shapers, equipped with quick return mechanism, often called the quick-return shaper mechanism, after the name of the machine tool in which it is used (the majority of shapers ever built have been crank shapers) [5], are the case study of the current research, in which, a coupling with a pre – determined misalignment is adopted. The main feature of the crank and slotted lever quick return motion, that it is capable of producing large time ratios [6-7]. It is often used in metal shaping machines to provide a slow cutting stroke and a quick – return stroke when the tool is doing no work [7]. Large time ratios can only be obtained by changing the machine stroke given that the other dimensions are kept intact such as the center distance of the flywheel and the limited stroke as well.

Slider – Crank mechanism is usually found in reciprocating steam engine mechanism as well as certain types of shaping machines [6]. This mechanism provides constant speeds for both the cutting and return strokes and speed ratio equals unity. However, Hsieh and Tsai [8] proposed a novel design for quick return mechanism and their new mechanism; composed by a generalized Oldham coupling and a slider – crank mechanism. Their design had been validated by kinematic simulation using ADAMS software and their study showed that the proposed mechanism is feasible and with reasonable accuracy. QRM has a very limited literature.

## 2.0 The goal of the research

This work aims to present an addition to the classical quick return mechanisms and verifying its feasibility by conducting computer simulation and theoretical analysis. A modified crank and slotted lever quick return motion mechanism is introduced consisting of adding coupling to the system as shown in figure (2). An intended misalignment ( $\delta$ ) using the parallel offset type will be used. DeSmidt et al [9] concluded that misalignment tends to stabilize internal damping-induced whirl, however, it causes instability of speeds within the revolution. The instability of speeds, as concluded by DeSmidt, agrees well with the current intended modification because it produces range of speeds for each revolution. This range is useful for controlling the speed of cut and return strokes. The main study parameters are as follows:

- a- the speed ratio ( $Q$ ), which can be defined as the ratio between the maximum return (back stroke) speed to the maximum cutting (forth stroke) speed [1], and
- b- the time ratio (TR), which can be defined as the ratio between the time elapsed for the cutting stroke to that of the back stroke [1-2].

## 3.0 Motion geometry

All quick – return mechanisms have time ratios either  $TR > 1$  or  $TR < 1$  according to the direction of motion of the flywheel, figure (2). Provided that, and stroke, the time ratio is constant. This research tends to introduce a mechanism by which, one can vary the speed and time ratio as required up to the limited range. Depends on the dimension of the machine, while keeping the direction of rotation and the stroke intact via using yoke mechanism as coupling with a pre – calculated misalignment between the two shafts being coupled, see figure (2) and figure (3). This task will be done by forcing the output shaft to rotate at different speeds for each revolution. Hence, the maximum speed of the ram (sliding block) may occur when it is either at the forward or backward.

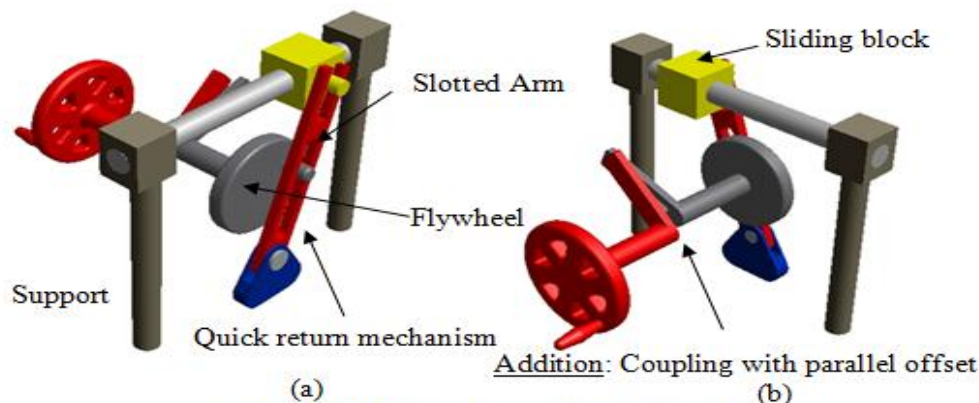


Figure (2) Modified Quick return mechanism

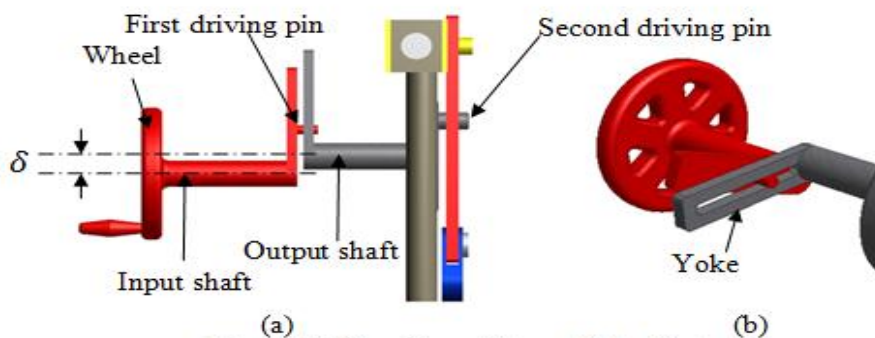


Figure (3) Coupling with parallel offset

### 4.0 Velocity analysis:

The mechanism shown in figure (3) is analyzed in a form of steps starting with input shaft and ending with the sliding block (ram) as follows:-

Step 1: Angular velocity calculation of the flywheel (output shaft):

Consider figure (4) below which illustrates the coupling geometry corresponding to figure (3 – b) above.

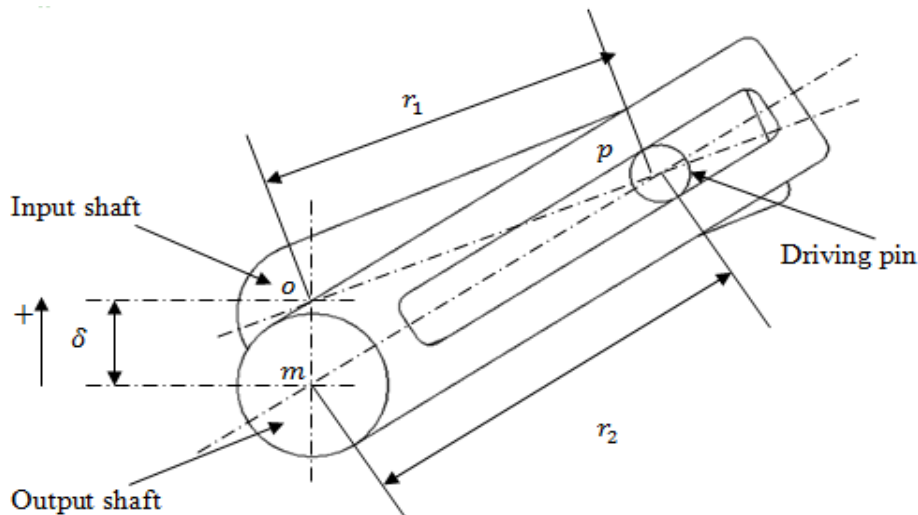


Figure (4) Coupling geometry

Where ( $r_1$ ) represents the distance from the center of the input shaft to the driving pin. ( $\delta$ ) is the pre-determined offset between the input shaft and the output shaft provided that the center of output shaft is the reference and hence it is positive upward, figure (4). ( $r_2$ ) is the distance from the center of output shaft to the driving pin and this is a time – varying distance during the operation due to the effect of the pre – determined misalignment . Consider the triangle  $\Delta o p m$ , ( $\beta$ ) is the angle determined by  $\angle m o p$ . From the cosine law, ( $r_2$ ) can be calculated as follows:

$$(r_2) = \sqrt{(r_1)^2 + \delta^2 - 2(r_1)(\delta) \cos \beta} \dots\dots\dots(1)$$

Now, the relation between the linear motion and angular motion is used for determining the angular velocity of the flywheel (i.e. the output shaft) [6-7]. Or,

$$v_1 = r_1 \times \omega_1 \dots\dots\dots(2)$$

$$v_2 = r_2 \times \omega_2 \dots\dots\dots(3)$$

Where ( $\omega_1$ ) is angular velocity of the input shaft and ( $\omega_2$ ) is the angular velocity of the output shaft. But  $v_2$  is corresponding to the perpendicular component of  $v_1$ , see figure (5) which is related to the geometry shown in figure (4), hence,

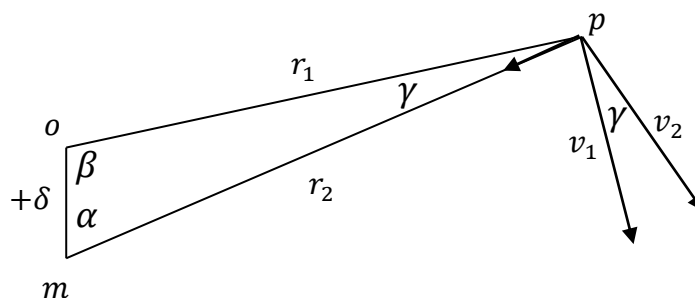


Figure (5) Coupling geometry

$$\omega_2 = \frac{v_2}{r_2} = \frac{v_1 \cos \gamma}{r_2} = \frac{r_1}{r_2} \omega_1 \cos \gamma = \frac{r_1 \cos \gamma}{\sqrt{(r_1)^2 + \delta^2 - 2(r_1)(\delta) \cos \beta}} \omega_1 \text{ -----(4)}$$

Note: The angular velocity ( $\omega_2$ ) determined by equation (4) will be equal to ( $\omega_1$ ) if the offset ( $\delta$ ) is zero.

Step 2: Angular velocity calculation of the slotted arm:

Now, consider figure (6). Once again, applying the cosine law on the triangle  $\Delta mab$  leads to the following formula for calculating the time – varying radius (R), or:

$$R = \sqrt{h^2 + s^2 - 2(h)(s) \cos \theta} \text{ .....(5)}$$

where ( $h$ ) is the distance between the lower pivot and the flywheel center. ( $s$ ) is the stroke of the crank. ( $\theta$ ) is the angle obtained by  $\angle bma$ .

The linear speed of the crank on the flywheel can be simply calculated as follows:

$$v_3 = s * \omega_2 \text{ .....(6)}$$

The crank causes the arm to rotate about ( $b$ ), fig. (6 – b). Due to the geometry of the quick return mechanism, ( $v_3$ ) is resolved in to two components, one of them is parallel to the slot of the arm and the other is perpendicular to the slot and the latter component is the main component that controls the motion of the arm.

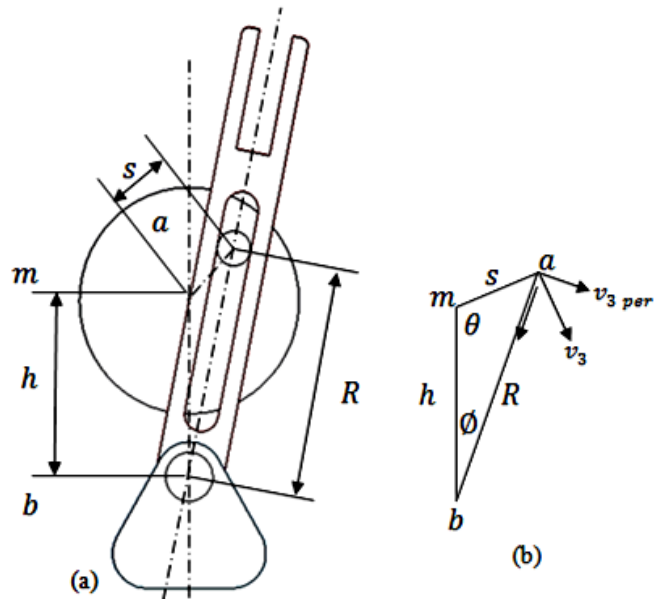


Figure (6) QRM geometry

Considering clockwise rotation, the perpendicular component ( $v_{3\ per}$ ) can be calculated as follows:

$$v_{3\ per} = v_3 \cos(180 - \phi - \theta) \text{ .....(7)}$$

Then, the angular velocity of the arm will be obtained as follows:

$$\omega_{arm} = \frac{v_{3\ per}}{R} = \frac{v_3 \cos(180 - \phi - \theta)}{R} \text{ .....(8)}$$

Step 3: Ram linear speed calculation:

The following relations obtained from fig (7) below:

$$v_{arm} = l \times \omega_{arm} \text{ .....(9)}$$

$$\text{and } l = \frac{H}{\cos \phi} \text{ .....(10)}$$

Substituting equations (8) and (10) into equation (9) gives:

$$v_{arm} = \frac{H}{\cos \phi} \frac{v_3 \cos(180 - \phi - \theta)}{R} \text{ .....(11)}$$

The component which is responsible for the motion of the ram is then:

$$v_{ram} = v_{arm} \cos \phi \text{ .....(12)}$$

Step 4: Determination of the speed ratio

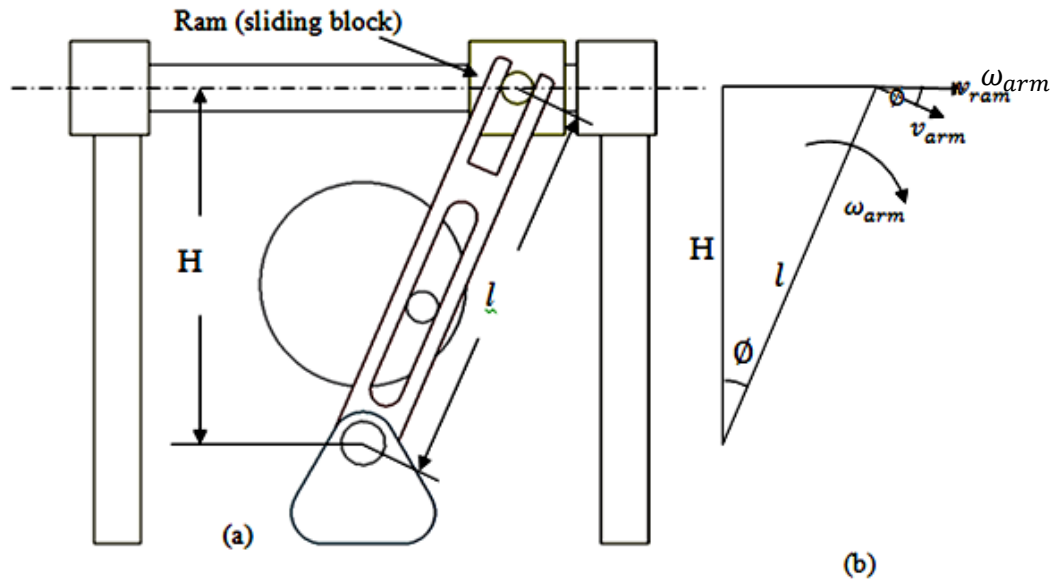


Figure (7) Front view of the modified QRM

The ram speed of shapers using quick return mechanism is divided into two categories, the forward (cutting) and backward (return or non – cutting or idle) speeds. Usually, the forward speed is less than the return speed. Then the speed ratio ( $Q$ ) in this case will be always greater than unity. However, using the present modified QRM, it will be possible to make the ram maximum forward speed equals, less or greater than the maximum backward speed. The relations for determining the maximum forward and maximum return speeds can be derived as follows:

1- The maximum forward (cutting) speed ( $v_c$ ):

This speed occurs at  $(\theta = \pi, 3\pi, 5\pi, \dots n\pi)$ , where  $(n)$  is an odd integer number, and it can be calculated using equations (4, 6 and 11) as:

$$v_c = \frac{H v_{3C}}{R_{max}} \dots\dots\dots(13)$$

where  $(R_{max} = h + s)$ , and  $(v_{3C})$  is the maximum speed of the second driving pin, fig (3 – a).

2- The maximum backward (return) speed ( $v_r$ ):

This speed occurs at  $(\theta = 0, 2\pi, 4\pi, \dots m\pi)$ , where  $(m)$  is an even integer number, and it can also be calculated as follows using eqs (4, 6 and 11) as:

$$v_r = \frac{H v_{3R}}{R_{min}} \dots\dots\dots(14)$$

where  $(R_{min} = h - s)$  and  $(v_{3R})$  is the maximum speed of the second driving pin. The speed ratio ( $Q$ ) can then be calculated using eqns (13) and (14):

$$Q = \frac{v_r}{v_c} = \frac{\frac{H v_{3R}}{h-s}}{\frac{H v_{3C}}{h+s}} = \frac{v_{3R}(h+s)}{v_{3C}(h-s)} \dots\dots\dots(15)$$



With zero offset, i.e. without the coupling,  $v_{3C} = v_{3R}$ , and equation (15) becomes:

$$Q = \frac{h+s}{h-s} \dots\dots\dots(16)$$

Step 5: Time ratio calculation:

Time ratio is very important in shapers if productivity time is considered [1-2]. The higher time ratios are always desired. Mathematically, the time ratio is:

$$TR = \frac{t_f}{t_b} \dots\dots\dots(17)$$

The time required for the cutting stroke, ( $t_f$ ) can be calculated from fig (8) as:

$$t_f = \frac{\alpha_1}{\omega_2} \dots\dots\dots(18)$$

where ( $\alpha_1$ ) is the time – varying angular displacement of the flywheel during the forward (cutting) stroke.

Similarly, the time required for the return stroke ( $t_b$ ) is:

$$t_b = \frac{\alpha_2}{\omega_2} \dots\dots\dots(19)$$

where ( $\alpha_2$ ) is the time – varying angular displacement of the flywheel during the backward (return) stroke.

If the offset is not zero then ( $\omega_2$ ) will not be a constant during a complete revolution as can be seen from equation (3) due to the presence of the coupling and misalignment. Equation (4) is simplified to the following first order differential equation:

$$\frac{d\alpha}{dt} - \frac{\cos(\sin^{-1}(\frac{\delta}{r_1} \sin \alpha))\omega_1 r_1}{\sqrt{(r_1)^2 + \delta^2 - 2(r_1)(\delta) \cos \omega_1 t}} = 0 \dots\dots\dots(20)$$

subjected to the following initial condition: at ( $t = 0$ ) , ( $\alpha = \pi$ ).

where  $\frac{d\alpha}{dt} = \omega_2$  and  $\omega_1 t = \beta$ .

Equation (20) can be solved numerically using Runge – Kutta 4<sup>th</sup> order method as in [10] and its solution led to find the time elapsed for both the forward stroke and the return stroke.

Step 6: offset calculation:

The magnitude of the required offset needs only specifying the speeds of the output shaft at two important positions, the first is at  $\beta = 0$  and the second is at  $\beta = \pi$ . The speed at  $\beta = 0$  will be denoted as ( $\omega_{2down}$ ) and the speed at  $\beta = \pi$  will be denoted as  $\omega_{2up}$ , then using equation (4):

$$\omega_{2down} = \frac{r_1}{r_1 - \delta} \omega_1 \dots\dots\dots(21)$$

substituting equation (21) into equation (8):

$$\omega_{armR} = \frac{S\omega_{2down}}{R} = \frac{S\omega_{2down}}{h-s} = \frac{S(r_1) \omega_1}{(r_1 - \delta)(h-s)} \dots\dots\dots(22)$$

where ( $\omega_{armR}$ ) is the angular velocity of the output shaft during the return stroke when ( $\theta = 0$ ).

For  $\omega_{2up}$  again using equation (4):

$$\omega_{2up} = \frac{r_1}{r_1 + \delta} \omega_1 \dots\dots\dots(23)$$

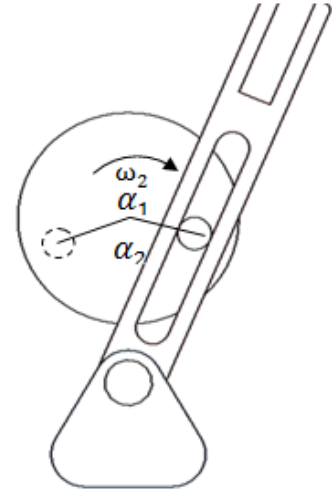


Figure (8) Time ratio

and by substituting equation (23) into equation (8):

$$\omega_{armC} = \frac{s\omega_{2up}}{R} = \frac{s\omega_{2up}}{h+s} = \frac{s(r_1)\omega_1}{(r_1+\delta)(h+s)} \dots\dots\dots(24)$$

where ( $\omega_{armC}$ ) is the angular velocity of the output shaft during the cutting stroke when ( $\theta = \pi$ ).

Now, dividing eq (22) by eq (24):

$$Q = \frac{\omega_{armR}}{\omega_{armC}} = \frac{\frac{s(r_1)\omega_1}{(r_1-\delta)(h-s)}}{\frac{s(r_1)\omega_1}{(r_1+\delta)(h+s)}} = \frac{(r_1+\delta)(h+s)}{(r_1-\delta)(h-s)} \dots\dots\dots(25)$$

Equation (25) is the formula for determining the speed ratio for any offset. For  $Q = 1$ , (i.e. for the case when the maximum cutting speed is equal to the maximum return speed) then:

$$\frac{(r_1+\delta)(h+s)}{(r_1-\delta)(h-s)} = 1 \quad , \text{ or}$$

$$\delta = \frac{-r_1*s}{h} \dots\dots\dots(26)$$

For any value of the speed ratio ( $Q$ ) the offset can be calculated by rearranging equation (25) and solving for the offset ( $\delta$ ):

$$\delta = \frac{r_1[Q(h-s)-h-s]}{Q(h-s)+h+s} \dots\dots\dots(27)$$

Equation (27) is useful for determining the required offset if the speed ratio is given.

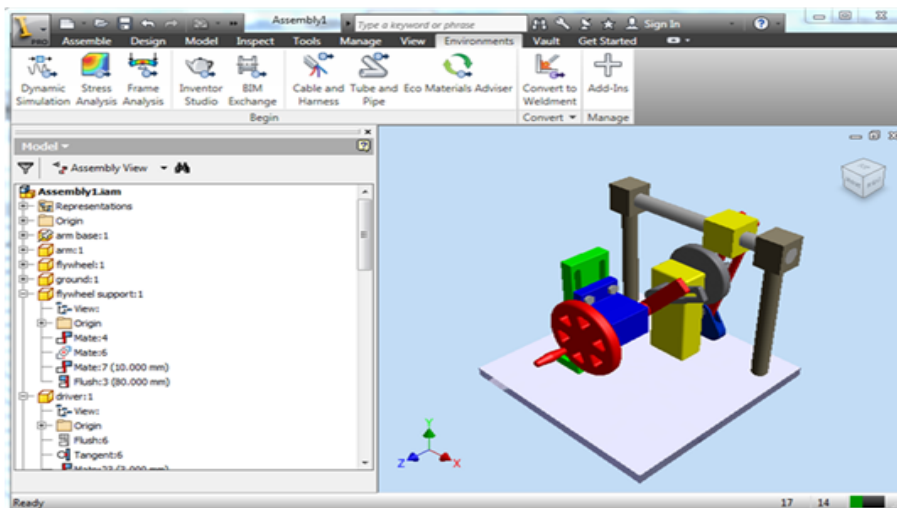


Figure (9) Autodesk Inventor Professional Software

**5.0 CAD modeling and simulation:**

Physical models can be built to illustrate the motion, and modular models using Tinker toy or Lego are also effective. However, the link lengths of these models are fixed to some extent, and the physical models can not represent many problems closely. Many software packages are available for linkage animation and analysis. To validate the present design, its solid model was established by Autodesk inventor software, as shown in figure (9) above. Then the model is introduced into Dynamic Simulation Environment included in the Autodesk Inventor. Table (1) shows the dimensions of the modeled mechanism. These dimensions also had been used in the theoretical and numerical analyses.

Table (1)

$r_1$ (mm)	$s$ (mm)	$h$ (mm)	$H$ (mm)	$\omega_1$ (rad/sec)
25	5-20	50.5	113	$2\pi$



### 6.0 Results and discussion

The modeled governing equations of the present mechanism had been programmed and solved using Matlab Software and their results are compared with the result of the simulation, which had been made using Autodesk Inventor Professional software. The following two sections present the main studied parameters, (*TR*) and (*Q*) and how they are influenced by the pre – determined offset. The third section is related to the speed calculation of the output shaft after applying the pre – determined offset.

#### 6.1 Effect of the offset on the time ratio:

Figure (10) shows time ratios for different flywheel strokes and for different offsets. The determination of the time ratios is obtained numerically by solving equation (20) and from simulation using Autodesk Inventor Professional Simulation Environment. For more clarity, a dimensionless parameter was chosen in terms of the offset ( $\delta$ ) and the height ( $h$ ), and it has the form  $(\delta/h)$ . The lowest black curve in figure (10) shows that when the stroke equals ( $s = 5 \text{ mm}$  and  $\delta/h = -0.05$ ) the time ratio was close to (1) and therefore the quick term in the quick return mechanism practically is not obvious. However, the time ratio changes significantly for the positive offsets and the quick term became practically obvious. The well agreement between the numerical and simulation results can be observed. Furthermore, eq (17) agreed well with the values shown in figure (10) for  $(\delta/h = 0)$  knowing that the time ratio for this case is:

$$TR_{\delta=0} = \frac{t_f}{t_r} = \frac{\alpha_1}{\alpha_2} = \frac{360 - 2 \times \cos^{-1}(s/h)}{2 \times \cos^{-1}(s/h)} \dots\dots\dots (28)$$

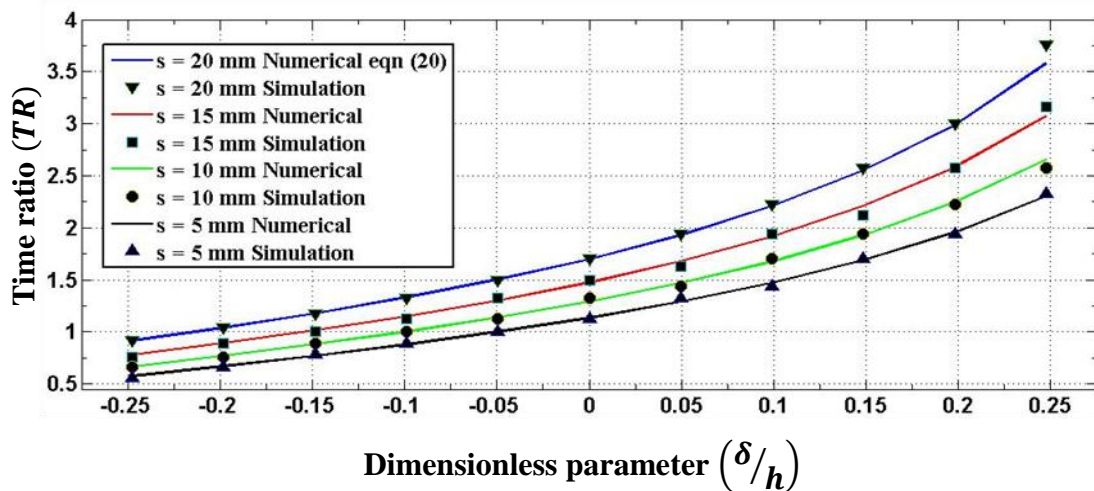


Figure (10) Time ratio Vs offset (numerical and simulation)

Furthermore, the time ratio is almost unity if the following condition is satisfied:

$$\delta = -\frac{s}{2} \dots\dots\dots(29)$$

#### 6.2 Effect of the offset on the speed ratio:

Figure (11) shows the speed ratios for both theoretical analysis using equation (25) and simulation analysis using Autodesk Inventor Professional software. A very good agreement between those analyses is observed. It is clear that doubling or halving the speed ratio is possible by choosing the right offset value. As mentioned earlier in the latter section, the values of offsets which give a unity speed ratio always occur at  $= -s/2$ .

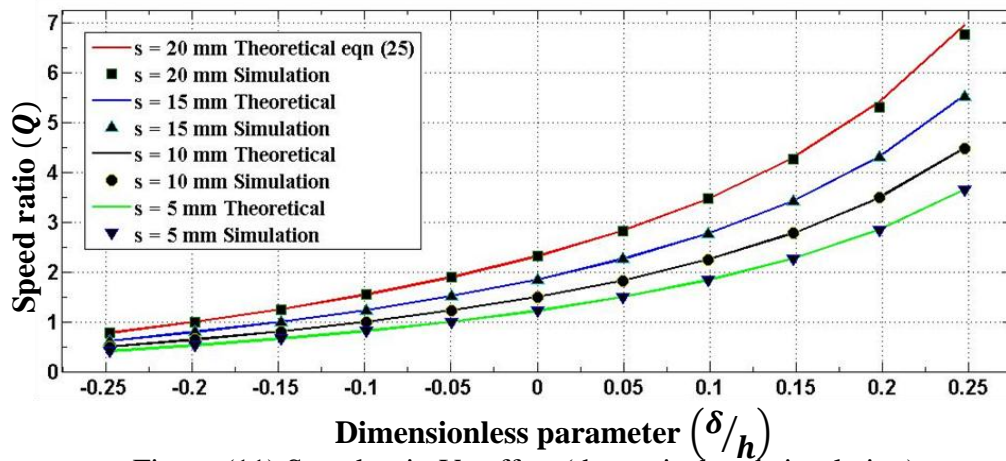


Figure (11) Speed ratio Vs offset (theoretical and simulation)

About changing the speed of cutting, it is possible to increase or decrease the speed of cutting via changing the offset while keeping the input shaft speed unchanged. A precise adjustment of speed is then possible by changing the offset as well as the gearbox. Thus, for each step of the gearbox there will be a range of speeds in order to meet almost the exact cutting speed which is important due to technical and economical reasons.

### 6.3 Effect of offset on the angular velocity of the output shaft:

Fig (12) shows the effect of the pre – determined offset on the angular velocity of the output shaft for two values of offset, 0 and – 10 mm for a complete revolution, (cut and return). The input speed is chosen to be ( $\omega_1 = 2\pi \text{ rad/sec}$ ).

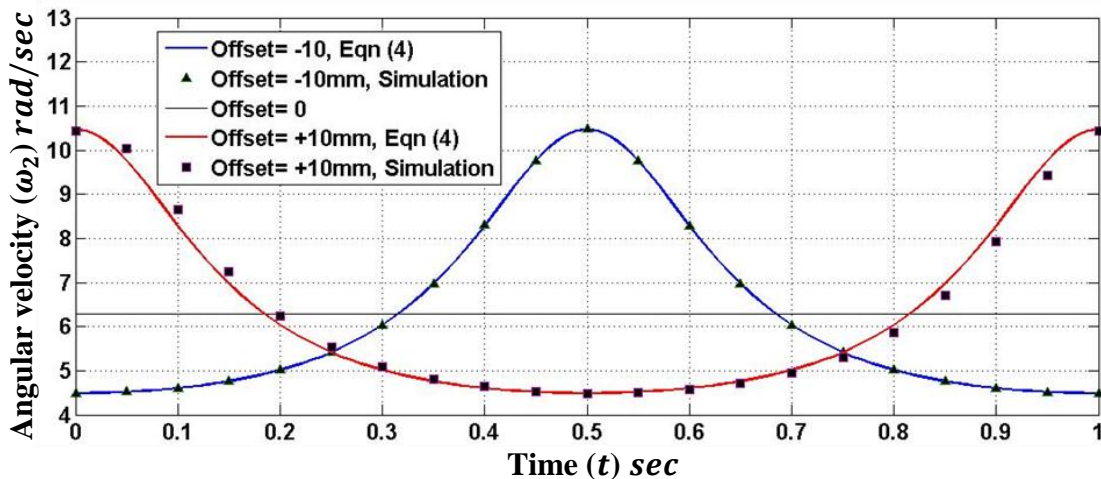


Figure (12) Comparison between theoretical and simulation for angular velocity of the output shaft during a complete

The blue curve (theoretical) and the black triangular marks (simulation) are for ( $\delta = -10$ ) as they started from a minimum value of the angular velocity because the motion initiated when the first driving pin, see figure (3 –a), was at its lower position. While the red curve (theoretical) and the squared marks (simulation) are for ( $\delta = +10$ ) as they started from a maximum value because the first driving pin was also at its lower position initially. Note that the horizontal black curve at ( $\omega_2 = 2\pi \text{ rad/sec}$ ) is corresponding to the case when the current modification is not used, i.e. zero offset.

## 7.0 Conclusion

The present study introduces a sort of a new mechanism equipped to the well known quick return mechanism, the shaper crank quick return mechanism. The effect of the offset on the time ratio is apparent especially if a comparison is made between the time ratios at  $\delta/h = 0$ ,  $\delta/h \cong -0.25$  and  $\delta/h \cong 0.25$ . Thus, it was possible to double or to halve the time ratio. Further conclusions are as follows:

- 1- It is possible to use yoke slot as coupling with a predetermined misalignment for varying the time ratio and the speed ratio while keeping the shaper ram stroke and the gearbox unchanged. Thus, a smaller gearbox with four speeds, for example, may be required instead of five speeds if the current mechanism is equipped to the machine. For the studied range and for this research, the shaft misalignment may be advantageous and good from an economic perspective.
- 2- For a very short stroke and without the current modifications, the return time is approximately equal to the cutting time. A noticeable increasing in the time ratio is observed with further increase of the offset in the positive direction.
- 3- For a given speed ratio, the magnitude of the pre – determined offset depends on the distance ( $r_1$ ), the stroke ( $s$ ) and the center distance of the flywheel ( $h$ ). This study enables finding the magnitude of offset required for obtaining the desired time ratio or speed of cutting. Furthermore, using shaft misalignment is expected to enhance productivity of the shaper since it leads to quicker return mechanism than the common used quick return mechanism.

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