Novel design for the adjustable knock-out mechanism with a Roberts linkage

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Abstract. This article presents a new adjustable knock-out mechanism of a bolt former with a Roberts linkage and an adjustable crank-rocker linkage. The design requirements of the new mechanism are based on the analysis of an existing adjustable knock-out mechanism. The new adjustable knock-out mechanism mainly consisting of a Roberts linkage, and an adjustable crank-rocker linkage is proposed to meet the specified requirements. The path of the knock-out screw is approximately a straight line and the method presented is illustrated by an example.

1. Introduction

A bolt former is a multistage press for cold forging of bolts [1]. Rod material fed by rollers is cut by a cutter when the required length is reached. It is then delivered to the first forging mold for the molding. Several stages have to be gone through before rod material could be gradually formed into the required shape. The shaping bolt and the forging mold are stuck together in each stage of molding, thus it is necessary to use the knock-out pin to knock the shaped bolt out of the mold after the molding process in each stage. In order to knock out bolts of different lengths, an adjustable knock-out mechanism is required to satisfy the need of variable knock-out strokes.

The concept design of adjustable knock-out mechanisms for the bolt former presented in the patent can be classified into two types: (a) adjustable linkages [2-4], and (b) adjustable cam-follower mechanisms [5-7]. An adjustable slider-crank linkage with an adjustable crank [2] is used to generate various knock-out strokes in bolt formers, but the extreme positions of the slider in various knock-out strokes are not the same. An adjustable four-bar linkage [3-4] is used in bolt formers to alter the knock-out stroke. The knock-out pin is driven by the output link of a four-bar linkage. The input link of the four-bar linkage is controlled by a cam. The link length of the input link can be adjusted to change the angle of the output link and knock-out stroke. Wang [5] proposed a knock-out cam-follower mechanism consisting of a knock-out pin, a swing cam, and an oscillating follower with a curved surface. The follower also serves as a pivoted lever arm for pushing the knock-out pin. The curved surface on the pivoted lever arm can be adjusted by two screws to generate various knock-out strokes. Tan [6] presented a knock-out cam-follower mechanism in which the follower of the mechanism includes two rollers; the cam can be adjusted to contact one roller or another in order to generate different stroke lengths. Yoshiichi [7] provided a knock-out cam-follower mechanism consisting of a cam-follower mechanism and a knock-out pin. The cam drives the oscillating roller follower to push the knock-out pin. The cam profile can be adjusted by an adjustment screw to...
generate various knock-out strokes to manufacture bolts of different lengths. Based on the concept stated above, a method is needed to design the cam profile with adjustment.

There are several approaches to design the cam profile without adjustment [8-14]. Hwang and Yu [15] presented an optimization method to design the cam profile with adjustment. For the cam profile with a sixth-degree polynomial segment, besides the six specified boundary conditions, a variable condition is used as a design variable of an optimization design. The kinematic characteristics of the new knock-out cam-follower mechanism synthesized are better than those of the existing mechanism.

The existing knock-out mechanisms [2-7] generally have two disadvantages: (1) The path of the knock-out screw is an arc, but the output of the knock-out mechanism required is a linear reciprocating movement for the knock-out pin; (2) The knock-out screw strikes the knock-out pin to make the noise. This article presents a new concept of adjustable knock-out mechanism with a Roberts linkage and an adjustable crank-rocker linkage. The path of the knock-out screw is approximately a straight line.

There are several approaches for the synthesis of linkage. Ahmad and Waldron [16] used an adjustable fixed pivot of the driven link to design adjustable four-bar linkages for motion generation. Krishnamoorthy and Kothadiya [17] presented a method to synthesize a four-bar linkage with an adjustable fixed pivot to obtain two intersecting straight lines. Wang and Sodhi [18] adjusted the moving pivot position of a four-bar linkage to generate multi-phase motion. Zhou and Ting [19] adjusted the position of the slider guider of a slider-crank linkage for multiple path generation. Wu and Chen [20] presented an adjustable four-bar linkage with an adjustable length link to synthesize linkages passing through more precision points. Zhou [21] adjusted the length of the coupler or the driven link for precise function generation. Pennock and Israr [22] presented an adjustable six-bar linkage with an adjustable input crank to synthesize the extreme positions of the output link and coupler link. An adjustable crank-rocker linkage is used to generate various oscillating angle of rocker in the new concept.

The purpose of this article is to propose a new adjustable knock-out mechanism in which the Roberts linkage generates straight knock-out paths and an adjustable crank-rocker linkage generates various strokes.

2. Design requirements of the knock-out mechanism

The knock-out mechanism of a bolt former used in a local company in Taiwan is shown in Fig. 1. It mainly consists of a crank-rocker linkage, an adjustable cam-follower mechanism, and a knock-out pin. The knock-out pin is struck forward by a knock-out screw on a pivoted lever arm. The pivoted lever arm is an oscillating roller follower controlled by a swing cam that is driven by the crank-rocker linkage. The cam profile can be adjusted around the adjustment axis to alter the starting position of the follower in order to generate various strokes of the knock-out pin. According to the kinematic analysis of the existing adjustable knock-out mechanism, the maximum strike velocity between the knock-out screw and knock-out pin is 1248.1mm/s when the knock-out stroke is 81.4mm. The horizontal component of the position of the knock-out screw for various knock-out strokes varied continuously from 81.4mm to 226.4mm [15].

According to the kinematic analysis of the existing adjustable knock-out mechanism, the design requirements for the new adjustable knock-out mechanisms are specified as follows:

(1) The horizontal component of the position of the knock-out screw for various knock-out strokes varied continuously from 81.4mm to 226.4mm (Fig. 2).
(2) All the extreme positions of the knock-out pin for different knock-out strokes are the same because the tongs catch different length bolts at the same location.
(3) The knock-out mechanism is driven by a DC motor.
(4) The output of the knock-out mechanism is a linear reciprocating movement of the knock-out pin.
(5) The motion of the knock-out pin must be controlled by a mechanism.
(6) The knock-out screw doesn’t strike the knock-out pin to eliminate the noise.
3. A new adjustable knock-out mechanism

Based on the functional requirements stated above, a new adjustable knock-out mechanism is presented below. The Roberts linkage must guide the knock-out screw to generate a straight-line path so as to satisfy the requirement for the linear reciprocating movement of the knock-out pin. Linkages generating a straight-line path are named straight-line linkages. Many popular straight-line linkages have been widely used for a long time [23]. The Roberts linkage is selected herein for the knock-out
mechanism. The Roberts linkage is driven by the rocker of a crank-rocker linkage $D_0DEA_0$. Therefore, the oscillating angle of link $A0A$ is the same as that of rocker $A_0E$. The Roberts linkage, with the dimensions that $A_0A=B_0B=AC=BC=a$, $AB=b$, and $A_0B_0=2b$, generates a coupler curve $\gamma_c$ as shown in Fig. 3. The straight-line portion of the coupler curve traced by the knock-out screw attached to the coupler point $C$ is suitable for guiding the knock-out pin. Because the final positions of the knock-out screw on the coupler curve for different knock-out strokes should be the same, the length of link $D_0D$ and $DE$ in the limiting position is adjustable by shifting pivot $D$ along line $D_0E$. The new adjustable knock-out mechanism proposed above consists of a Roberts linkage and an adjustable crank-linkage for knocking out bolts of different lengths by adjusting the lengths of link $D_0D$ and link $DE$.

4. Synthesis procedure
In order to satisfy the kinematic requirements stated above, a procedure for synthesizing the dimensions of the new adjustable knock-out mechanism is presented as follows:

(1) Specify the design demands of the knock-out mechanism, e.g., the required maximum and minimum knock-out strokes, $S_{\text{max}}$ and $S_{\text{min}}$, the working range $\Delta \phi$ of the crank $D_0D$, and the starting angle $\phi_0$ of the crank $D_0D$.

(2) Construct the mathematical model of the position deviation of coupler point $C$ from the desired straight line as follows: Adjust the length of link $DE$ from $c_1$ to $c_1+\Delta d$; the length of link $D_0D$ is thus $a_1+\Delta d$. The adjusted linkage will generate a smaller oscillating range. The coordinates of coupler point $C$ can be expressed as follows:

\[
x_c(\theta_2) = a \cos \theta_2 + a \cos \left( \theta_2 - \cos^{-1} \left( \frac{b}{2a} \right) \right)
\]

\[
y_c(\theta_2) = a \sin \theta_2 + a \sin \left( \theta_2 - \cos^{-1} \left( \frac{b}{2a} \right) \right)
\]

Where

- $\theta_2$ is the angular positions of link $A_0A$
- $\theta_3$ is the angular positions of link $AB$

\[
\theta_3 = 2 \tan^{-1} \left[ - E + \sqrt{E^2 - 4DF} \right] / 2D
\]

\[
D = \cos \theta_2 - k_1 + k_2 \cos \theta_3 + k_3
\]

\[
E = -2 \sin \theta_2
\]

\[
F = k_1 + (k_2 - 1) \cos \theta_3 + k_3
\]

\[
k_1 = \frac{2b}{a}
\]

\[
k_2 = 2
\]

\[
k_3 = -\frac{(a^2 + 4b^2)}{2ab}
\]

The knock-out stroke $S$ is the difference of the x coordinates of coupler point $C$ between the starting and final positions, and can be written as:

\[
S = x_c(\theta_{3s}) - x_c(\theta_{3f}) = b - a \cos \theta_{3s} - a \cos \left( \theta_{3f} - \cos^{-1} \left( \frac{b}{2a} \right) \right)
\]

Where $\theta_{3s}$ and $\theta_{3f}$ are the starting and final angular positions of link $A_0A$, respectively. $\theta_{3s}$ is the starting angular position of link $AB$.

(3) For a specific knock-out stroke $S_{\text{max}}$, design the link lengths of an Roberts linkage and the total oscillating range $\Delta \varphi_{\text{max}}$ of rocker $A_0E$.

(4) For a specific knock-out stroke $S_{\text{min}}$, design the total oscillating range $\Delta \varphi_{\text{min}}$ of rocker $A_0E$. 
(5) According to the total oscillating angle $\Delta \psi_{\text{max}}$ of the rocker $A_0E$, the working angle $\Delta \phi$ of the crank $D_0D$, and the starting angle $\phi_0$ of the crank $D_0D$, synthesize the link lengths of the adjustable crank-rocker linkage which controls the motion of the Roberts linkage. The link lengths can be written as [24]:

$$a_i = \left[ -\sin \Delta \psi_{\text{max}} \frac{\Delta \phi}{\sin \frac{\Delta \psi_{\text{max}}}{2}} \cos \left( \frac{\phi_0 + \Delta \phi}{2} \right) \right] f_i$$

$$b_i = \left[ \frac{\sin(\phi_0 + \Delta \phi)}{f_i} - \frac{\sin(\phi_0 + \Delta \phi - \Delta \psi_{\text{max}})}{f_i} \right] f_i$$

$$c_i = \left[ \frac{\sin(\phi_0 + \Delta \phi - \Delta \psi_{\text{max}})}{f_i} - \frac{\sin(\phi_0)}{f_i} \right] f_i$$

(6) According to the total oscillating angle $\Delta \psi_{\text{min}}$ of the rocker $A_0E$ and the lengths of the crank $D_0D$, rocker $A_0E$, coupler link $DE$, and fixed link $D_0A_0$, synthesize the adjustable value $\Delta d$ of crank $D_0D$ [24]:

$$\Delta \psi_{\text{min}} = \cos^{-1} \frac{b_i^2 + f_i^2 - (a_i + c_i)^2}{2f_i} - \cos^{-1} \frac{b_i^2 + f_i^2 - (c_i - a_i + 2\Delta d)^2}{2f_i}$$

Example: Design a Roberts knock-out mechanism shown in Fig. 2 to satisfy the following design requirements: (a) the maximum knock-out stroke is 226.4mm, (b) the minimum knock-out stroke is 81.4mm, (c) the working range of the crank $D_0D$ is 150.4$^\circ$, and (d) the starting angle of the crank $D_0D$ is 55.6$^\circ$.

(1) For a specific knock-out stroke $S_{\text{max}}$ is 226.4mm, design the link lengths of an Roberts linkage and the total oscillating range $\Delta \psi_{\text{max}}$ of rocker $A_0E$ is 16.6$^\circ$. The link lengths $a$ and $b$ are 500mm and 500mm, respectively.

(2) For a specific knock-out stroke $S_{\text{min}}$ is 81.4mm, design the total oscillating range $\Delta \psi_{\text{min}}$ of rocker $A_0E$ is 5.5$^\circ$.

(3) Substituting $\Delta \psi_{\text{max}}=16.6^\circ$, $\Delta \phi=150.4^\circ$, and $\phi_0=55.6^\circ$ in Eqs. (5)–(7), the link lengths of the crank $D_0D$, rocker $A_0E$, coupler DE, and fixed link $D_0A_0$ are 102.5mm, 845.4mm, 278.6mm, and 1000mm, respectively.

(4) Substituting $a_1=102.5mm$, $b_1=845.4mm$, $c_1=278.6mm$, $f_1=1000mm$, and $\Delta \psi_{\text{min}}=5.5^\circ$ in Eqs. (8), the adjustable value $\Delta d$ of the crank $D_0D$ and coupler DE is 63.8mm. The value of $\Delta d$ is from 0mm to 63.8mm, corresponding to a knock-out stroke from 226.4mm to 81.4mm.

5. Conclusions
This paper presents a method for the configuration design and dimensional synthesis of an adjustable knock-out mechanism of a bolt former with a Roberts linkage. This adjustable knock-out mechanism has the following advantages:

(1) This article presents a creative concept of adjustable knock-out mechanism with a Roberts linkage. The path of the knock-out screw is approximately a straight line.

(2) A new adjustable knock-out mechanism is used to eliminate the noise, because the knock-out screw doesn’t strike the knock-out pin.

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