Modelling and Simulation Based on Matlab/Simulink: A Press Mechanism

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Abstract. In this study, design and kinematic analysis of a crank-slider mechanism for a crank press is studied. The crank-slider mechanism is the commonly applied one as direct and indirect drive alternatives in practice. Since inexpensiveness, flexibility and controllability are getting more and more important in many industrial applications especially in automotive industry, a crank press with servo actuator (servo crank press) is taken as an application. Design and kinematic analysis of representative mechanism is presented with geometrical analysis for the inverse kinematic of the mechanism by using desired motion concept of slider. The mechanism is modelled in MATLAB/Simulink platform. The simulation results are presented herein.

1. Introduction
Forming process is a mechanical deformation without removing or adding any part is significant in industry. Sheet metal and bulk metal forming processes are often used in automotive sectors [1-2]. The process’ device is hydraulic and mechanical presses. While hydraulic presses provide directly flexibility, conventional mechanical presses are more reliable and accurate, provide flexibility with their mechanisms such as linkages and screw [3-5]. Studies have condensed on servo presses with evolution of servo motor for several decades. The servo press is a mechanical press that has been actuated by servo motors. The most important advantage of servo presses possesses the positive properties of hydraulic and conventional mechanical press [4-5]. Miyoshi [6] represented the recent appearance of servo presses was an epoch-making event that would change and expand the possibility of press production techniques. Also he gives Komatsu’s servo press types and comparison of the press types’ motion. Osakada et al [4] have presented a detailed study on servo presses technology and metal forming. Kiper [5] has prepared a review study on servo presses in the industry. Their another study is about input design of servo hybrid presses with cardan gear [7]. Tokuz and Jones [8] have offered a hybrid actuator which is composed from one servo driven actuator and one conventional motor (has constant velocity). Their hybrid configuration is considered as first hybrid actuator system, and is fundamental of hybrid servo presses [8-9]. Sun et al [10] have discussed on AC servo presses’ further develop trends and key problems. Although there are a lot of press mechanisms in literature and industry, commonly used mechanism in industry is crank-slider mechanism. Servo crank presses are preferred generally because of their suitable sizes, ease of manufacturing, long and adjustable strokes, cheapness, etc. Servo presses are been by mechanisms. Because of designing of a mechanism, kinematic and dynamic analyses are required. The analysis can be modeled numerical or by having a software. Serbest et al [11] have modeled a motion of a person’s sitting and upping via...
Matlab/SimMechanics tool box. Liu et al [12] have designed a dynamic model of slider-crank mechanism without external forces by Matlab/Simulink. Nagchaudhuri [13] has studied on slider-crank mechanism too. Fung et al [14] have presented kinematic and dynamic analyses of two different slider-crank mechanisms.

In the study, a motion scenario adaptable to servo crank press has been selected and kinematic analysis of the scenario on the mechanism has been applied. A Simulink model is presented with simulation results.

2. Free Motion Concept
The most important difference between conventional and servo presses is flexibility of the motion. While motion characteristic of conventional presses is provided by mechanism design, motion characteristic of servo presses is provided by control of the actuator. Infinite motion scenario can be created by control unit from a mechanism. The property gain flexibility of motion such as hydraulic presses. Flexible motion of servo presses is presented as free motion concept by Miyoshi in 2004 [6]. Comparison of the motion characteristic between the conventional press and the free motion press can be seen in figure 1. Process time interval in conventional presses is longer than servo presses. Press manufacturers have many motion selection parameters such as crank, knuckle soft, silent, link, pulsating, programmable, pendulum, coining, stop, iterative, etc [15-17]. Some of the servo press motion concepts are given at figure 2.

![Figure 1. Comparison of a conventional eccentric-drive press (blue) and servo-mechanical press (red) [18].](image1)

![Figure 2. Some motion concepts of servo presses [4].](image2)

3. Case Study
3.1. Press Mechanism and Motion Scenario
Servo crank press is selected for the study. Definition of the mechanism is that crank length, crank angle, rod length, rod angle, slider position are given with parameters \( r, \theta, l, \beta, y \) respectively such as figure 3. The slider crank mechanism’s rod-crank ratio is selected as six. The stroke of mechanism is 700mm, in-line mechanism’s crank length must be 350mm, and the rod length is six time of it as 2100 mm. The soft motion scenario is created by MATLAB/Curve Fitting tool box [19] is given in figure 4.

3.2. Kinematic Analysis
Vectorial expression of mechanism is given as equation (1).

\[
\overrightarrow{OB} = \overrightarrow{OA} + \overrightarrow{AB}
\]

\[
y = r \cos \theta + l \cos \beta
\]

\[
o = r \sin \theta - l \sin \beta
\]
First and Second derivatives of equations (1) and (2) are taken and written in a matrix form to give velocities and accelerations such as equation (4) and (5):

\[
\begin{bmatrix}
 l \sin \beta & 1 \\
 l \cos \beta & 0
\end{bmatrix}
\begin{bmatrix}
 \dot{\theta} \\
 \dot{y}
\end{bmatrix}
=\begin{bmatrix}
 -r \dot{\theta} \sin \theta \\
 r \dot{\theta} \cos \theta
\end{bmatrix}
\]  \hspace{1cm} (4)

\[
\begin{bmatrix}
 l \sin \beta & 1 \\
 l \cos \beta & 0
\end{bmatrix}
\begin{bmatrix}
 \ddot{\theta} \\
 \ddot{y}
\end{bmatrix}
=\begin{bmatrix}
 -(r \ddot{\theta} \sin \theta + r \dot{\theta}^2 \cos \theta + l \dot{\beta} \cos \beta) \\
 r \dot{\theta} \cos \theta - r \dot{\theta}^2 \sin \theta \dot{\beta} + l \dot{\beta}^2 \sin \beta
\end{bmatrix}
\]  \hspace{1cm} (5)

Inverse kinematic analysis is necessary to gain the crank position for desired slider motion profile. Geometrical analysis is performed for the inverse kinematic of the mechanism.

\[
x^2 = r^2 - (y - l \cos \beta)^2 = l^2 - (y - r \cos \theta)^2 \quad , \quad x = r \sin \theta
\]  \hspace{1cm} (6)

\[
\cos \theta = \frac{r^2 + y^2 - l^2}{2yr}
\]  \hspace{1cm} (7)

Stroke “s” of crank press mechanism is written as;

\[
s = y - l + r
\]  \hspace{1cm} (8)

If \( y \) is substituted from equation (7) to equation (8);

\[
\theta = \cos^{-1} \left[ \frac{r^2 + (s + l - r)^2 - l^2}{2r(s + l - r)} \right]
\]  \hspace{1cm} (9)

Equation (9) gives crank angle. The first and second derivatives of equation (9) give the crank velocity and acceleration respectively.

4. Modelling of the Mechanism

Model of the mechanism is presented by MATLAB/Simulink tool box [19] using the equations (2-5) as figures 5 and 6. The equations can be solved directly by using the model. Figures 7 represents the servo motion of crank mechanism and figure 8 gives the slider’s output motion is desired scenario.

5. Conclusions

The crank-slider mechanism is modelled by using Matlab/Simulink platform. It is possible to extend motion scenarios for slider with servo inputs. An example motion is explored with inverse kinematics. Simulation results are presented for its possible application. They give the desired motion concept.
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