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Kinematic Analysis of a Variable Speed Deep Drawing Press Using GIM Software

Manar AlJaimaz[1], Zahraa AlMazidi[1], Haya AlDousari[1], Fatmah Ebrahem[1], Danah AlZayyan[1], Eddie Gazo Hanna[1,*]
[1] College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait
42200@aum.edu.kw; 43987@aum.edu.kw; 44651@aum.edu.kw; 44971@aum.edu.kw; 52795@aum.edu.kw;
eddie-hanna@aum.edu.kw

Abstract **-** In this paper, we introduce a groundbreaking method to enhance the functionality of a Stevenson-type press by manipulating the input speed of the crank. Unlike the traditional approach of maintaining a constant input speed, we propose a novel strategy that involves varying the speed of the output sliding ram. Our approach utilizes a servomotor as the power input, allowing us to achieve the desired trajectory of the output motion by carefully designing the input speed using Bezier curves. To obtain the desired output position, velocity, and acceleration, we employ dimensional synthesis on GIM software. Design examples are given for illustration.

Keywords**:** Stevenson mechanism, deep drawing process, dimensional synthesis, GIM software.

1. Introduction

The Stevenson-type press mechanism, named after its inventor Robert Stevenson, is a specific type of mechanical press mechanism widely used in various industrial applications, including deep drawing processes [1]. Stevenson developed this mechanism with the goal of achieving improved control and efficiency in forming operations [2]. It is highly regarded for its simplicity and reliability, making it a popular choice in manufacturing [3]. The key characteristics of the Stevenson-type press mechanism include its design comprising a crankshaft, connecting rod, and sliding ram [3], [4]. The crankshaft, driven by a motor, converts rotary motion into reciprocating linear motion, while the connecting rod transmits this motion from the eccentrically mounted crank to the vertically moving ram [3], [4]. The sliding ram, guided vertically, acts as the actuating element and exerts the necessary force on the workpiece [3], [4]. During operation, the crankshaft imparts reciprocating motion to the connecting rod and ram. The downward stroke moves the ram towards the workpiece, applying force for processes like deep drawing, while the upward stroke retracts the ram in preparation for the next cycle [3], [4]. The rotational speed of the crankshaft can be controlled to adjust the speed and force of the ram's movement, and the stroke length can be adjusted to accommodate different workpiece sizes and forming requirements [3], [4].

Adjusting the forming speed allows for better process control and optimization, resulting in improved precision and reduced defects during forming operations [5]. Different materials require specific forming speeds, and the ability to accommodate various materials through crank input speed variation ensures optimal material flow and deformation [6]. By controlling the forming force through speed adjustments, delicate materials can be protected from damage, leading to improved product quality[5], [7]. Furthermore, the optimization of the crank input speed for specific applications enables efficient and timely completion of forming processes [5]. The flexibility provided by varying the crank input speed also contributes to minimizing wear and tear on press components, prolonging equipment lifespan and reducing maintenance requirements [7].

The purpose of this study is to show that, using GIM software, we are able to design a variable speed input crank mechanism that yields output results comparable to those obtained from a constant speed crank mechanism.
The objective is to create a practical input speed trajectory that allows for variation. This is accomplished by utilizing Bezier curves to define the trajectory. In addition, dimensional syntheses and kinematic analysis are conducted to attain the desired output motion characteristics that are comparable to those achieved with a constant speed crank mechanism. By employing these techniques, we aim to design a feasible and effective variable speed approach that can be implemented successfully.

2.Bezier curve

Since the input link of the press is a crank undergoing a circular rotation, we define the displacement trajectory of the crank by an *nth* order Bezier curve $\theta_2(t)$, as shown in Fig. 1: The Stevenson mechanism vector loop diagram., with parameter *t* as:

$$\theta_2(t) = \sum_{i=0}^{n} \theta_{2,i} B_{i,n}(t) + \theta_{2U} \tag{1}$$

Where:

$\theta_2(t)$	is the crank angle
θ_{2U}	is the crank angle when the slider reaches its upper position at *t* = 0
n	is the Bezier curve order
$B_{i,n}(t)$	is the Bernstein polynomial.

$$B_{i,n}(t) = \frac{n!}{i!\,.\,(n-i)!} \times t^i \times (1-t)^{n-i} \qquad t \in [0,1] \tag{2}$$

A notable benefit of selecting a Bezier curve as the motion trajectory is its property of being nth order differentiable, ensuring a smooth motion throughout. As a result, we can derive the angular velocity $\omega_2(t)$ and acceleration $\alpha_2(t)$ of the input link by continuously differentiating equations 1 and 2 with respect to time:

$$\omega_2(t) = \frac{d\theta_2(t)}{dt} = \sum_{i=0}^{n} \theta_{2,i} \frac{dB_{i,u}(t)}{dt} \tag{3}$$

$$\alpha_2(t) = \frac{d^2\theta_2(t)}{dt^2} = \sum_{i=0}^{n} \theta_{2,i} \frac{d^2B_{i,u}(t)}{dt^2} \tag{4}$$

Where:

$\omega_2(t)$	is the crank angular velocity
$\alpha_2(t)$	is the crank angular acceleration.

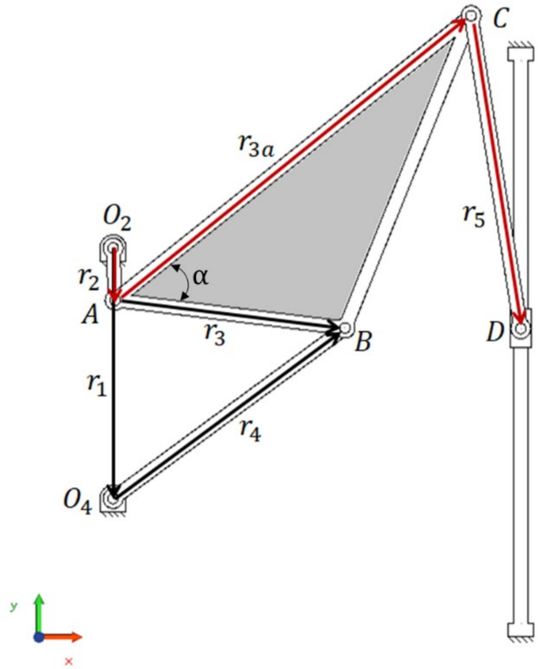

Fig. 1: The Stevenson mechanism vector loop diagram.

3.Methodolgy

Kinematic analysis and dimensional synthesis of the Stevenson-type press were performed using GIM software This software, developed by the COMPMECH Research Group at the University of the Basque Country (UPV/EHU) in Spain, to support educational activities focusing on key subjects within the field of mechanical engineering. These subjects encompass applied mechanics, mechanism and machine theory, computational kinematics and dynamics, mechanical design, and robotics. The software's design caters to the needs of students and educators by providing a platform for teaching and learning, facilitating a comprehensive understanding of these important disciplines. It offers tools and resources that aid in exploring and grasping the principles and concepts associated with these subjects, thereby enhancing the educational experience in mechanical engineering [8] . GIM software offers a systematic and automated approach to mechanism synthesis, utilizing geometric constraints, GIFs, parameterization, optimization, and analysis to efficiently design mechanisms that satisfy desired criteria.

3.1. Constant speed crank Stevenson mechanism

The Stevenson six-bar press mechanism [9], has a binary link as its ground link, and consists of two loops defined by joint coordinates: (i) a 4-bar linkage O_2ABO_4, and (ii) a slider crank linkage O_2ACD. We start from the press, whose dimensions are $r_1 = 400$, $r_2 = 135.92$, $r_3 = 369.84$, $r_4 = 459.78, r_{3a} = 628.07, r_5 = 213.04, \alpha = 9.5° \; and$ running at average crank speed 60 rpm. The corresponding input and output motion characteristics are shown in Fig. 2 and Fig. 3.

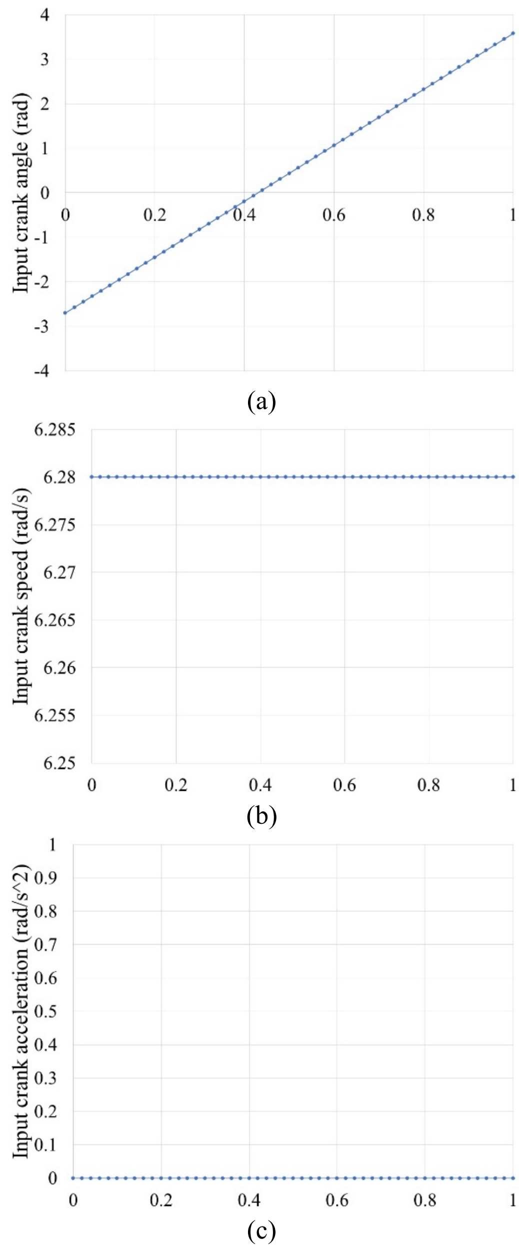

Fig. 2: Input crank (a) Position, (b) velocity, and (c) acceleration

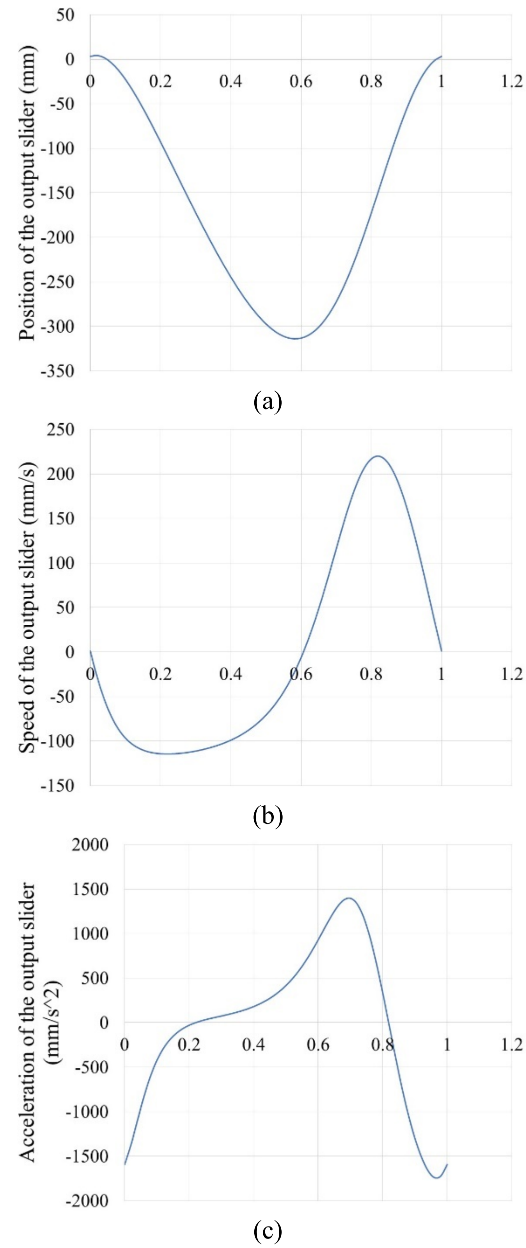

Fig. 3: Output slider (a) Position, (b) velocity, and (c) acceleration

Figures 2(a), 2(b), and 2(c) present the input crank angle, input crank angular velocity, and input crank angular acceleration, respectively. Upon analysing these figures, it becomes apparent that the angular velocity remains constant throughout the observed time period. Consequently, the angular acceleration is observed to be zero. Similarly, Fig. 3(a), 3(b), and 3(c) illustrate the output slider position, output slider velocity, and output slider acceleration, respectively. By examining these figures, a notable observation emerges during the time interval from 0.1 to 0.5. Within this period, it becomes evident that the slider maintains an almost constant velocity. As a direct consequence, the slider's acceleration during this time interval is nearly zero.

3.2. Variable speed crank Stevenson mechanism

A 10th order Bezier curve is employed and using a special optimization method, the corresponding input characteristics characteristics are shown in Fig. 4.

Dimensional synthesis was performed using GIM software. This software employs advanced optimization algorithms algorithms to search for the optimal values of the geometric parameters that satisfy the defined constraints and criteria. The resulting dimensions are $r_1 = 270.12$, $r_2 = 51.28$, $r_3 = 153.50$, $r_4 = 244.55, r_{3a} = 302.22, r_5 = 366.25, \alpha = 3.5°$. The corresponding output characteristics are shown in Fig. 5. It is important to observe that the dotted curves presented in Figs. 4 and 5 depict the motion under constant input conditions, serving as a basis for comparison.

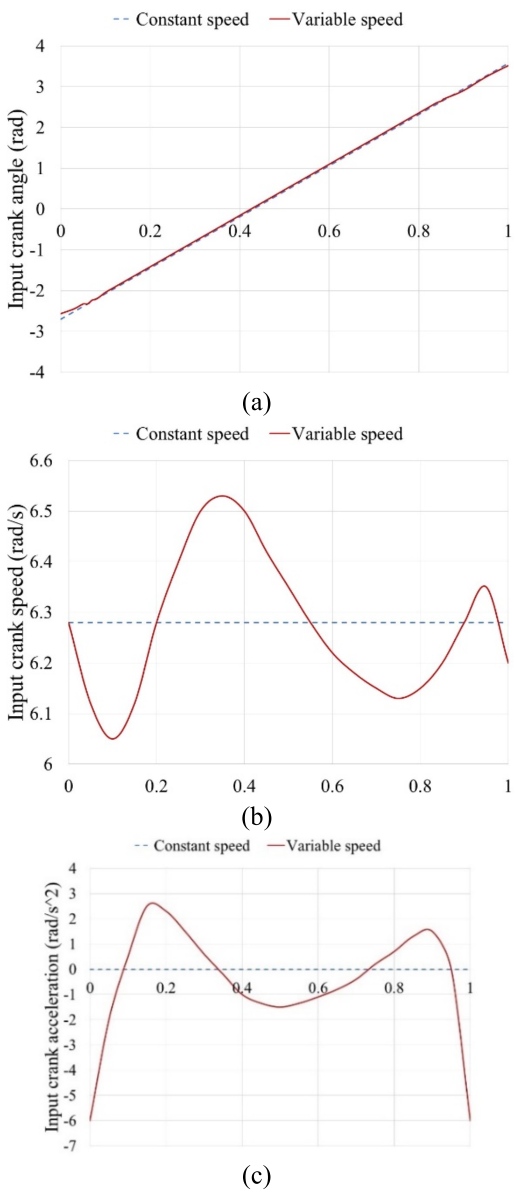

Fig. 4: Input crank (a) Position, (b) velocity, and (c) acceleration

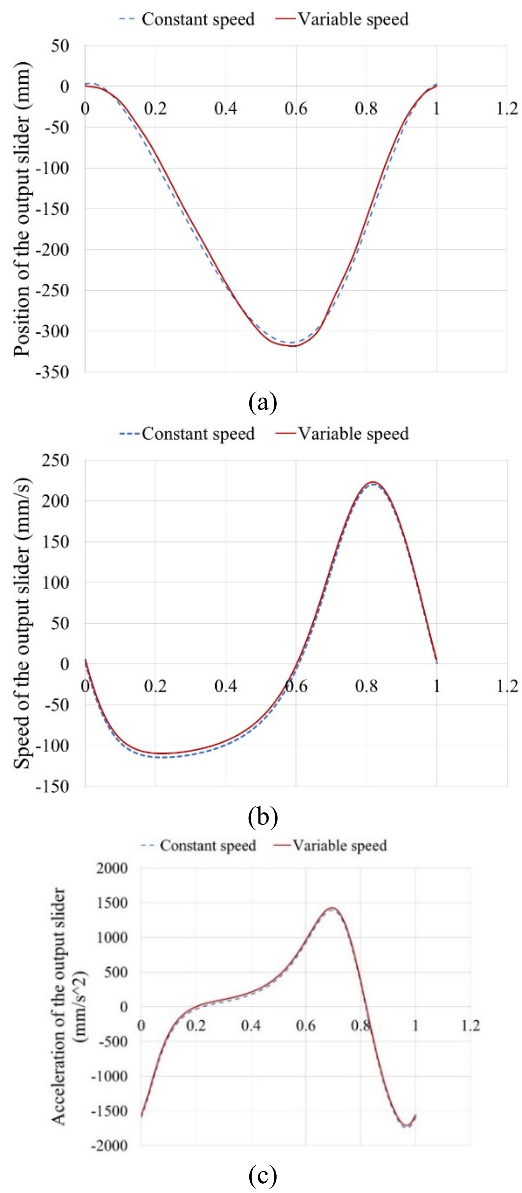

Fig. 5: Output slider (a) Position, (b) velocity, and (c) acceleration

Figures 4(a), 4(b), and 4(c) provide insights into the input crank angle, input crank angular velocity, and input crank angular acceleration for both constant speed and variable speed cases. Similarly, Fig. 5(a), 5(b), and 5(c) showcase a remarkable correspondence in the results of the output crank position, output crank velocity, and output crank acceleration for both constant speed and variable speed cases. The observed correspondence signifies that our method enables the design of a variable speed input crank mechanism that produces output results comparable to those achieved with a constant speed crank mechanism.

4. Conclusion

In conclusion, this study aimed to demonstrate the feasibility of designing a variable speed input crank mechanism using GIM software, while achieving output results comparable to those obtained from a constant speed crank mechanism. Through the utilization of Bezier curves to define the input speed trajectory, combined with dimensional syntheses and kinematic analysis, the desired output motion characteristics were successfully attained. The findings of this study support the creation of a practical and effective variable speed approach that can be implemented successfully.

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