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Simulation of Metal Flow to Investigate the Application of Antilock Brake Mechanic System in Deep Drawing Process of Cup

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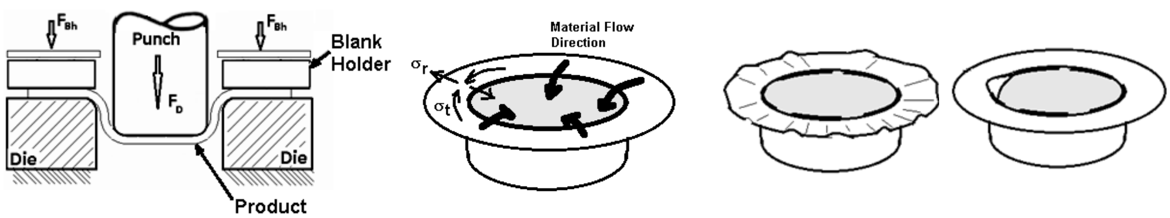
ABSTRACT This paper presents the importance of simulation of metal flow in deep drawing process which employs an antilock brake mechanic system. Controlling the force and friction of the blank holder is imperative to assure that the sheet metal is not locked on the blank holder, and hence it flows smoothly into the die. The simulation was developed based on the material displacement, deformation and deep drawing force on flange in the radial direction, that it is controlled by blank holder with antilock brake mechanic system. The force to blank holder was applied periodically and the magnitude of force was kept constant during simulation process. In this study, the mechanical properties of the material were choses such that they equivalent to those of low carbon steel with its thickness of 0.2 mm. The diameter and the depth of the cylindrical cup-shaped product were 40 mm and 10 mm, respectively. The simulation results showed that the application of antilock brake mechanic system improves the ability to control the material flow during the drawing process, although the maximum blank holder force of 13000 N was applied. The optimum condition was found when the drawing process was performed using blank holder force of 3500 N, deep drawing force of 7000 N, friction coefficient of 0.25 and speed of punch stroke of 0.84 mm/sec. This research demonstrated that an antilock brake mechanic system can be implemented effectively to prevent cracking in deep drawing process.

Introduction

A drawing process refers to a sheet metal forming process where a sheet metal is radially drawn into a forming die by implementing a mechanical action of punch. It is called “deep drawing” when the depth of the drawn part exceed the diameter of the product. Although this process has been known and used for many years, there are many problems that may occur during the process and still become the attraction of many researchers. The process of deep drawing and problems that often occur in this process are illustrated in Figure 1.



(a) **(b)** **(c)**

Figure 1. (**a**) Process of drawing deep; (**b**) Flow of material and stress deformation; (**c**) Crack and wrinkle defect.

Controlling the flow of material properly during a deep drawing process is very important in order to prevent product defects such as wrinkling and cracking. Endelt, B [1] investigate the application of a flexible blank-holder system to adjust the blank-holder pressure individually in different zones in the flange area [1]. The draw-in of the flange is influenced by the blank-holder pressure and therefore, the draw-in can be controlled by adjusting/controlling the pressure. Online drawn-in measurement can be performed using laser technology in which its sensors based on mechanical devices. However, this method requires sensors and equipment that are not applicable to the industry.

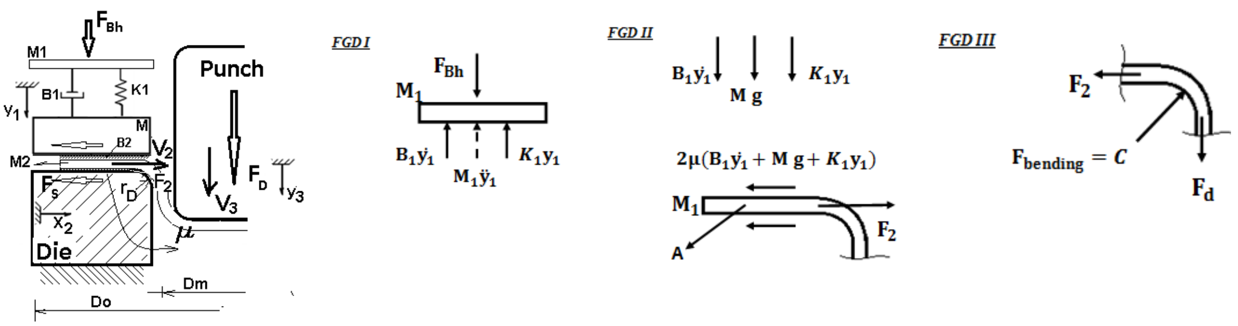
The magnitude of the blank holder force is an important factor in the forming process and hence the proper magnitude has to be determined properly. In this study, a variable blank holder force (VBHF) approach to deep drawing is employed [2][5][6]. This study provides information about the optimal gap to prevent wrinkling of the material, which will be used as data in this simulation. It was found that the optimal gap is no more than 117% the thickness of the material [2].

Gavas, M., studied the use of a simple mechanical antilock brake system (ABS) to control the material flow in deep drawing process [3][4]. The experiment proved that the additional mechanism helps to ease the flow of the material into the die yield to the possibility of deeper drawing process. However, the importance stage prior to experimental process, i.e. simulation, was not performed. Therefore, investigating various materials having different material properties as well as dimensions would be very difficult and expensive. It is due to different arrangement of system and most likely different equipment are needed in order to perform such different experiment set-up and test.

Based on the description above, it is clear that the control of blank holder force is an important parameter that must be considered. Therefore this paper will discuss about the application blank holder with anti lock brake system, in order to further optimize the flow of material towards the radial (not locked) and tangential (not too fast). The results of this study present the material flow simulations using a blank holder with antilock brake system, as has been done by M Gavas [4]. Validation of the method by comparing the simulation results with Gavas's experiment, related to the condition of material flow and material formability.

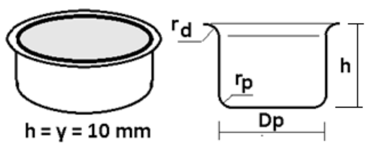
System Equation

Simulation model of anti-lock system in the process of deep drawing requires the development of material flow equations between the surface of the die and blank holder, the function of blank holder force and the condition of the process. The free body diagram (FGD) of deep drawing process and product dimensions are illustrated in Figure 2a and 2b, respectively.



a

Fbh: Blank Holder Force; Fd: Deep Drawing Force; B1: Damping coefficient 1; K1: spring coefficient; B2: damping coefficient 2; M1: Weight of Upper Plate; M2: Weight of material low carbon steel; M: Weight of Blank Holder Plate; V2: Velocity 2; V3: Velocity 3, Fs: Friction Force; μ: Friction coefficient.



b

Figure 2.a. FGD of deep drawing on cylindrical products, b. Product dimensions

Based on FGD 1 in Figure 2.a. the equation of blank holder force can be determined as follows:

$$F_{Bh} = M_1\ddot{y}_1 + B_1\dot{y}_1 + Ky_1 \quad (1)$$

F_{Bh} represents the force that controls the flow of metal into the die. The magnitude of restraining force (F2) can be drawn from the equilibrium of force in flange as shown in FGD II of Figure 2.a.

$$F_2 = M_2\,\ddot{x}_2 + 2\mu(M_1\ddot{y}_1 + B_1\dot{y}_1 + Ky_1 + M\,g) + B_2\dot{x}_2 + A \qquad (2)$$

Here, the variable "A" is the ideal stress deformation (deformation factor), which is obtained from the following equation:

$$A = \pi.D_m.s_o\, e^{\mu\,\pi/2}\{1.15\sigma_o\,(\frac{x_2}{r_m})\} \qquad (3)$$

where, σ_o is the material yield stress, D_o is the initial blank diameter, D_m is the mean diameter, s_o is the thickness of material; μ is the coefficient of friction and x_2 is the position of material flows for a moment after pressure is applied.

Deep drawing force is the sum of tensile force on the flange and bending force on die radius, and therefore, the equation of deep drawing force is:

$$F_d = M_2\,\ddot{x}_2 + 2\mu(M_1\ddot{y}_1 + B_1\dot{y}_1 + Ky_1 + M\,g) + 2B_2\dot{x}_2 + \pi.D_m.s_o e^{\mu\,\pi/2}\{1.15\sigma_o(\frac{x_2}{r_m})\} + \pi.D_m.s_o\,\{\frac{\sigma_o s_o}{2r_D}\} \qquad (4)$$

Having $\sigma_o = 309$ N/m^2, D_o= 56,7 mm; ro = 28.35, D_p = 40 mm; s_o = 0.2 mm; D_m= Dp+s_o=40.2 mm; r_D= *die radius* = 1 mm, substituting equation (1) into (4), the movement of flange modeling yields:

$$\ddot{x}_2 = \frac{1}{M_2}\{F_d - 2\mu(M_1\ddot{y}_1 + B_1\dot{y}_1 + Ky_1 + M\,g) - 2B_2\dot{x}_2 - 446.32\, e^{1.57\mu}(x_2) - 780.07\} \qquad (5)$$

Equation (5) is used as a mathematical model of the simulation system for the application of blank holder by using antilock braking mechanic system.
The flow of material on the surface of the flange and into the die follows the rule of constant volume, and the following relationship can be obtained:

$$x_{2d} = \frac{1}{0.8}x_3 \text{ and } V_{2d} = \frac{1}{0.8}V_3 \qquad (6)$$

and then,

$$y_{3d} = 0.8\, x_{2d} \text{ and } V_{3d} = 0.8\, V_{2d} \qquad (7)$$

Deep Drawing Equipment With Antilock Brake System Application [3][4]

The design and the development of deep drawing with the anti lock brake mechanic system is shown in Figure 3 [3][4].

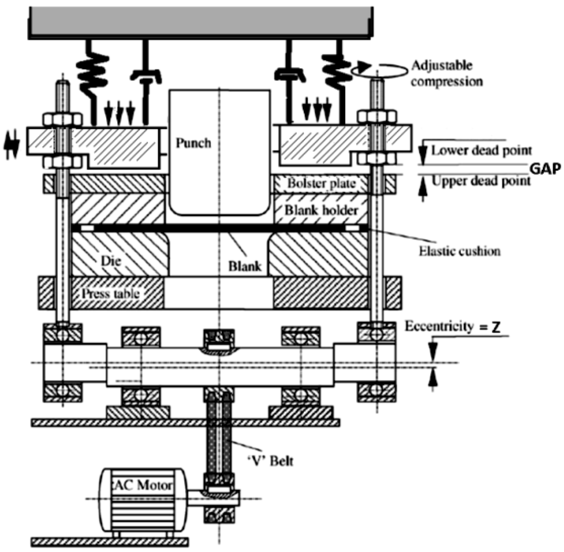


Figure 3 Scheme of deep drawing machine using application of blank holder with anti lock brake system [3][4]

If the path of shaft in the radial direction of eccentric was approached with a sinusoidal equation, therefore eccentricity Z can be described as an amplitude. While setting the distance gap represents a shift graphic of sinusoidal up and down, therefore the sinusoidal trajectory of eccentric axis would represent the mechanism of anti lock braking/hammering mechanic system. And with these mechanisms system, the deep drawing force (Fd) can be modelled independently. As well as the simulation modelling would describe the influence of blank holder Force (Fbh) against the movement of flange and the metal forming. Then, refers to the equation (5) above and the mechanism of anti lock brake system, furthermore the algorithm programming/ simulation block diagram is created.

Block and Computer Simulation

A block diagram for dynamic simulation of the mechanism of anti-lock brake system can be formed using equations 4 and 5, and the results are illustrated in Figure 4.a. The model parameters used for simulation are given below.

Meterial of blank sheet: low carbon steel sheet;	μ = coefficient of friction = 0.25 (palm oil)
Gap= ± 5 mm following reference [1] and [2];	x_2 = The position of flange
M2= 1 N (weight of blank sheet);	M_1= 500 N (weight of blank holder plate)
B_1 = 600 Ns/mm (value of damping coefficient);	B_2 = 100 Ns/mm (value of damping coefficient on flange surface)
K_1= 1000 N/mm (value of spring coefficient);	F_{bh} = 3500 N; Fd= 7000 N (average of Deep Drawing Force)
σ_o = 309 N/m^2;	D_o = 56,7 mm; r_o= 28.35; D_m = 40.2 mm
s_o = 0.2 mm; r_D = *die radius* = 1 mm;	Dp= 40 mm

Figures 4.b and 4.c show the simulation result of deep drawing process, i.e. the blank holder displacement and velocity, respectively. It can be seen that both displacement and velocity of blank holder when the drawing process is performed using anti lock brake system are lower than it is performed without anti lock mechanism. It is due to the fact that the application of anti lock mechanism allows the metal to flow more freely since the magnitude of displacement and velocity are influenced by the applied force on the blank holder.

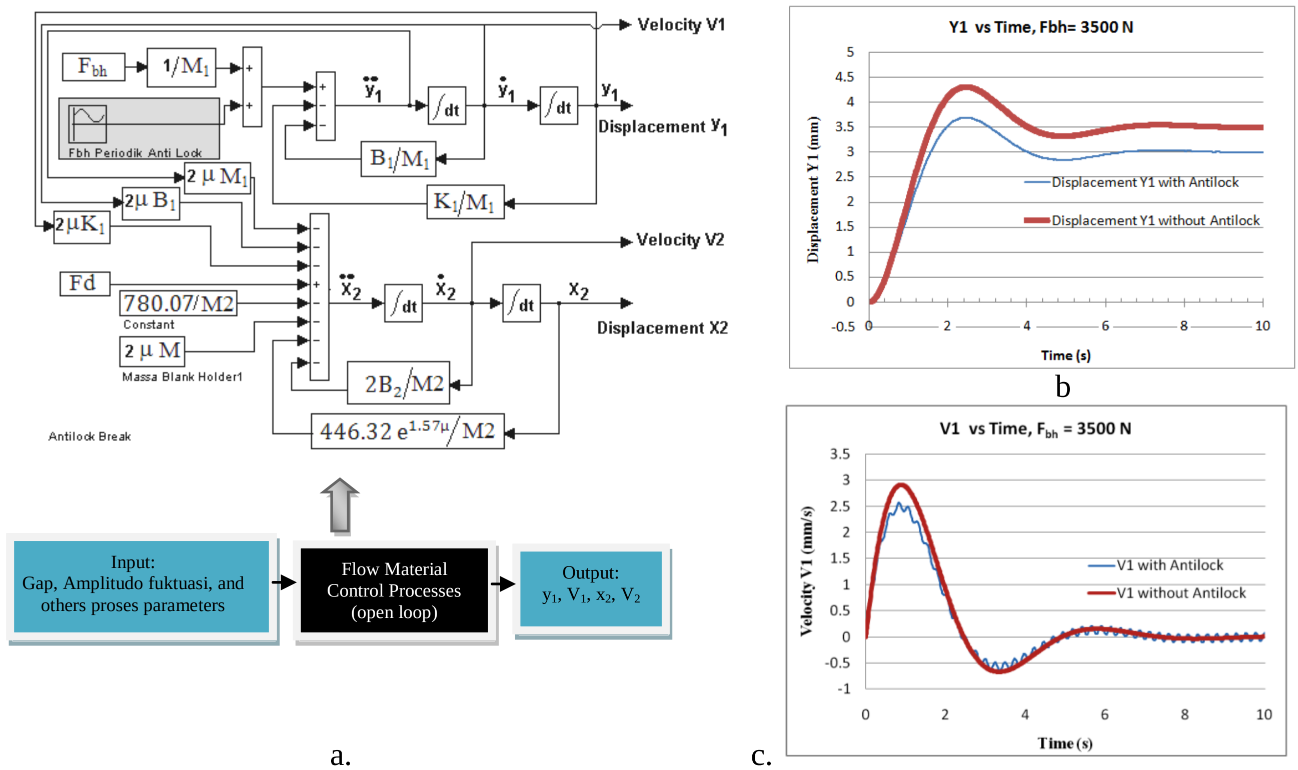
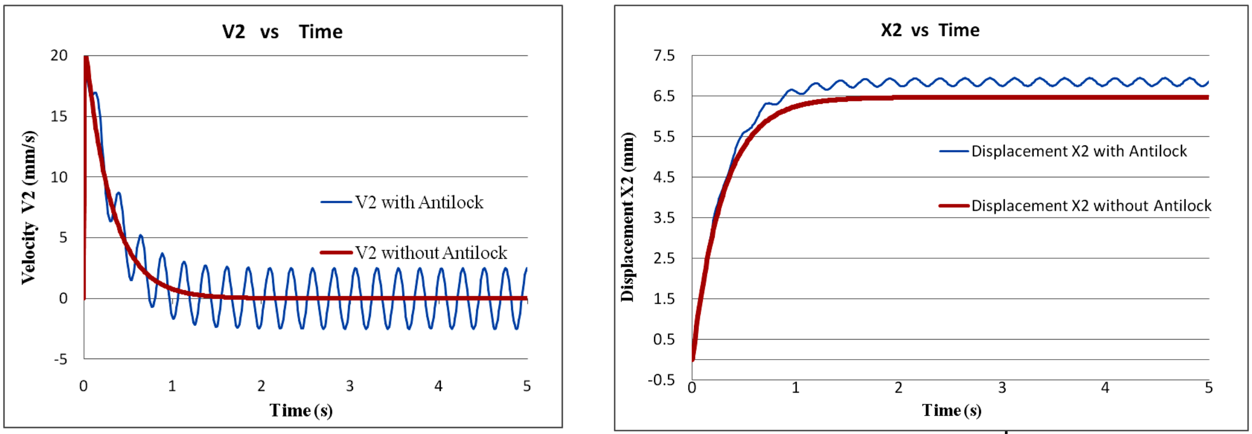


Figure 4.a. Block diagram of simulation the material flow by using the antilock brake systems, b and c. Displacement y_1 and velocity V_1.

Results and Discussions

Figure 5 illustrate the simulation of the drawn material which it flows is not obstructed when the antilock braking system is used in the system. The results show that the material displacement (x2) on the flange reach approximately 6.9 mm and the speed of punch stroke of 0.84 mm/sec. It can be observed that the displacement of the flange can only reach less than 6.4 mm when the antilock braking system is not employed. Increasing in flange displacement lead to increasing in material formability, and in this case, the formability increases by 30%. Similar results were indicated by Gavas's experiment [3][4]. He also proved that the applications of antilock braking system blank holder yields increases of material formability.



a b

Figure 5. **a.** The Graphic of velocity (on Blank Holder) V_2 with and without antilock; **b.** Displacement graphic of sheet material in the flange (x_2)

Figure 6 shows that although the applied holder force reaches its highest magnitude of 13000 N, the antilock braking system still quite effective to avoid locking in the material flow. It means that the system is capable of controlling flow of material under a very high holding force. In order to optimize the application blank holder on this system, and to improve the ability to avoid locking in the flow of materials, the gap between the upper dead point and lower dead points (see Figure 3) shall be adjusted properly. All the simulations results above agree with the experiment of application anti-lock brake system that was performed by Gavas [3][4], and hence his method can be considered feasible for production.

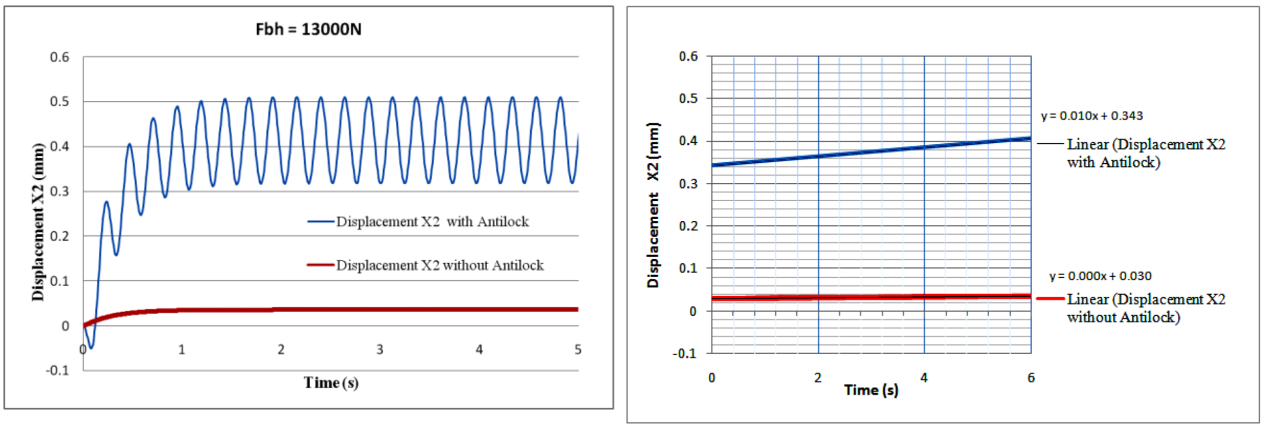


Figure 6. The Displacement of material in the flange (x_2) with the magnitude of F_{bh} 13000 N.

Summary

The application blank holder with antilock brake systems to control the material flow is one of the alternative methods to prevent sheet material to wrinkle and/or crack. The simulation results showed that these system capable of controlling the flow of material smoothly even though the value of blank holder force reaches the maximum value of 13000 N. It was suggested that the optimum value of blank holder force is set approximately 3500 N, deep drawing force of 7000 N, friction coefficient of 0.25 and speed of punch stroke of 0.84 mm/sec. The anti-lock brake system would increas the material formability up to 30%. An open loop brake mechanics system has been implemented, however several drawbacks were noticed. The simulation results also showed that a closed loop system can be employed to improve the performance of the implemented open loop brake mechanics system.

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