Application of Modern Cushion Systems to Improve Quality and Productivity in Sheet Metal Forming

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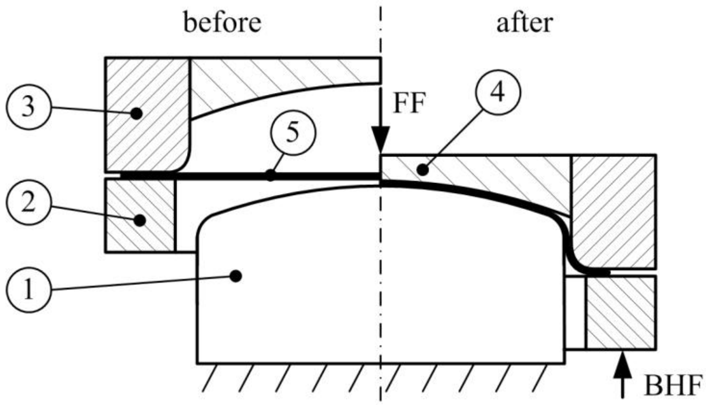
CIRP Conference on Process Machine Interactions-Vancouver, Canada
June 10-11, 2010

Abstract: In deep drawing of large automotive panels or stainless steel sinks the use of multiple point cushion (MPC) systems are well accepted to improve metal flow and part quality. The optimum distribution of blank holder force (BHF) components upon various hydraulic or nitrogen cushion pins requires extensive experimentation or die try-outs or could be estimated by FEA simulation. This paper reviews various practical MPC systems, discusses the results obtained from FEA predictions and how they compare with experimental observations. Finally, a robust and practical closed loop MPC control strategy is suggested, that makes use of the comparison of the FEA estimated flange geometry with that obtained during actual production.

Keywords: sheet metal forming, multi point cushion system, optimization

1 INTRODUCTION

Deep drawing of sheet metal is used to form parts by a process in which a flat blank is constrained by a blankholder while the central portion of the sheet is pushed into a die opening with a punch to draw the metal into the desired shape without causing wrinkles or splits in the drawn part [Demeri, 2001], Figure 1.



1	punch
2	blank holder
3	die ring
4	die insert
5	blank
BHF	blank holder force
FF	forming force

Figure 1 Deep drawing tooling on single action press

In deep drawing and sheet hydroforming, the properties of the formed part are determined by the amount of material drawn into the die cavity during forming. An excess material flow or insufficient blank holder force (BHF) will trigger wrinkling while insufficient material flow will cause tearing in the part. Material flow into the die cavity is primarily regulated by the force applied by the blank holder.

Most of today's deep drawing operations are carried out in single action presses with a cushion system either integrated in the press or in the tooling. The cushion system generates the blank holder force (BHF) and transmits it to the blank holder. Conventionally, nitrogen cylinders, hydraulic cylinders or pneumatic cylinders are employed to apply a constant blank holder force through the press stroke [Altan et al., 2006b]. Pneumatic systems have several disadvantages. They show a high peak BHF in the moment when the press slide hits the blank holder; the BHF is dependent on the forming speed and the available cushion force is relatively low. The principle of nitrogen cylinder is similar to pneumatic cushions, however, instead of compressed air, compressed nitrogen gas is used as a pressurizing medium. Due to relatively small volume of gas contained the pressure generated in nitrogen cylinders does not increase as fast as in pneumatic cylinders. Hydraulic systems have a higher load density compared with gas cylinders and allow for better force control with stroke. Therefore, they are mostly employed for forming of larger parts. Figure 2 shows a standard hydraulic cushion system with 4 hydraulic cylinders on the corners of the pressure pot. Recently, servo-mechanical cushion systems are proposed. The cushion force can be freely changed with stroke. Every time the die cushion is used the power can be recovered, Figure 3.

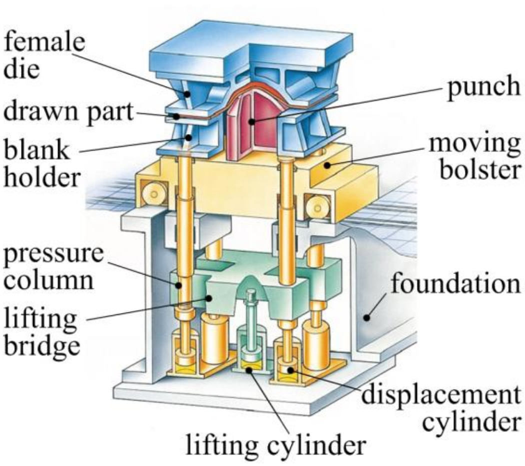


Figure 2; Standard hydraulic cushion system [Schuler, 1998]

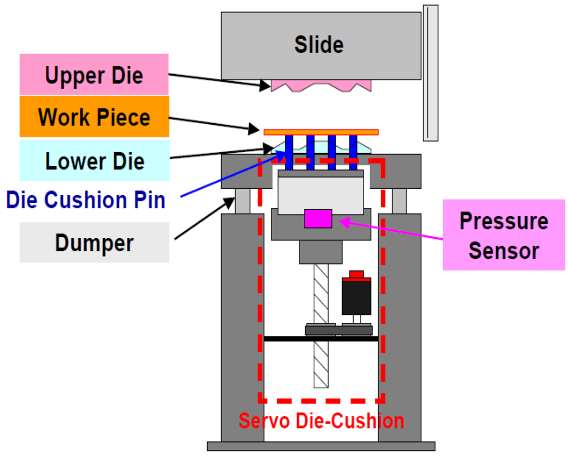


Figure 3; Schematic of a Servo mechanical cushion system with energy recovery [GE/Fanuc, 2001]

Conventionally, the BHF is applied uniformly on the blank holder surface and is held constant with stroke. Therefore, it is practical to obtain the optimum blank holder force by trial and error, through finite element (FE) simulations or in die try-outs. Many investigations have shown that an optimized blank holder force (BHF) profile, which varies in time/stroke and space/location, can improve the drawing process for parts with complex geometry by providing a better control of the metal flow. Increasing complexity of the parts and emphasis to use lightweight materials with low formability require the use of multi-point cushion capabilities to better control the material flow and expand the processing window [Altan et al., 2006].

2 FACTORS AFFECTING FORCE FLOW IN CUSHION SYSTEMS

Numerous research studies and the experience in the factory floor describe the interactions between cushion system and the process [for example, Kirri et al 1995; Pahl, 1997; Hohnhaus et al 2000; Großmann et al., 2007; Braedel et al., 2008].

In a single action press, part of the force applied by the die is transmitted through the sheet to the blank holder, from the blank holder through the pins to the pressure box. The pressure box is supported by one or more cylinders, which generate the blank holder force on the sheet. Since all machine parts are more or less elastic, the elastic deformation of the parts involved in the force flow affect the blank holder force distribution on the sheet, often at an unacceptable level [Pahl, 1997].

Asymmetric part design and/or off-center mounted tools in single slide transfer presses cause asymmetric loading. As a consequence press slide and die tilt occur. This affects the contact between sheet and blank holder, resulting in higher normal to surface pressure at certain locations and a loss of contact in other areas, depending on the direction of tilting.

The pressure box of a cushion system carries the cushion pins, which transmit the force to the blank holder. The set-up of cylinders underneath the pressure box, affects the location of its largest deflections. In case of four supporting cylinders, the maximum deflection can be found in the middle of the pressure box. The pins located in this area can loss contact with the blank holder which results in a non uniform pressure distribution on the blank holder surface [Hohnhaus et al 2000].

The blank holder sits on cushion pins, which are in contact with the pressure box. A variation of their length (due to fabrication tolerances or wear) and a relatively stiff blank holder cause only the taller pins to transmit the force between blank holder and pressure box. This leads to higher blank holder pressure in areas with larger cushion pins. In extreme cases different pin heights could also result in tilting of the press slide and the pressure box [Kirri et al 1995; Pahl, 1997].

[Großmann et al., 2007; Braedel et al., 2008] show how to address elastic deflections of the die cushion during forming analysis. Furthermore, [Braedel et al., 2008] states that an asymmetric distribution of draw beads leads to off-centered clamping forces, which can also result in a deflection of the cushion system. Consequently, the largest clamping gap was observed at locations with two rows of draw beads.

3 MULTI-POINT CUSHION SYSTEM

Multi-point cushion (MPC) systems mostly consist of several individually programmable hydraulic cylinders, which apply the force directly to the blank holder. MPC systems are either integrated in the press (see Figure 5) or in the tooling (see Figure 4). Thus they allow varying the BHF in location and during the stroke. This enables the manufacturer to better control the material flow into the die cavity by adjusting the blank holder pressure profile to suit different stamping geometries. This prevents wrinkling, tearing and reduces thinning throughout the part [Altan et al., 2006b]. By varying the BHF with stroke the manufacturers can improve the springback behavior of the formed part. The variation of the BHF at different locations enhances the drawability of the stamping. Furthermore, the factors described in Chapter 2 have only little influence on the blank holder pressure distribution, which increases the reproducibility [Pahl, 1997]. The MPC systems also allow adjusting the distribution of the blank holder pressure on sheet metal variations occurring from coil to coil.

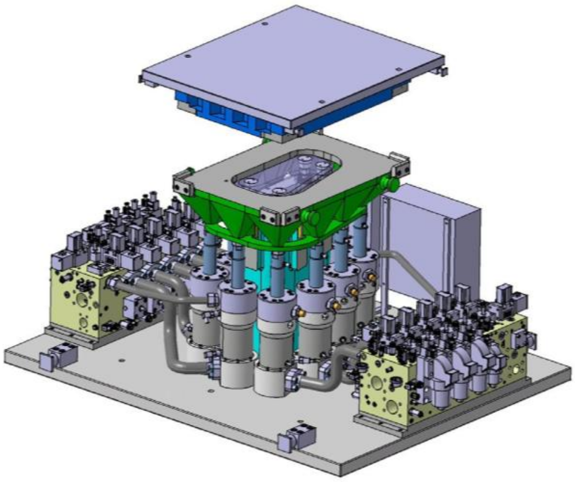


Figure 4; Multi-point cushion system with segment-elastic blank holder mounted in the tooling [Wagner et al., 2004]

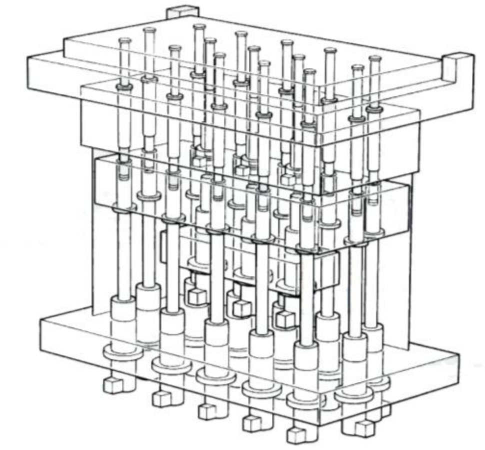


Figure 5; Multi-point cushion system integrated in press table [Schneider, 1991]

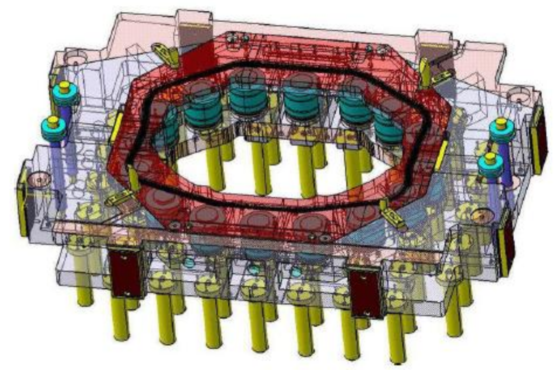


Figure 6; In-die multi-point cushion system with Nitrogen Cylinders [Rittmeier, 2007]

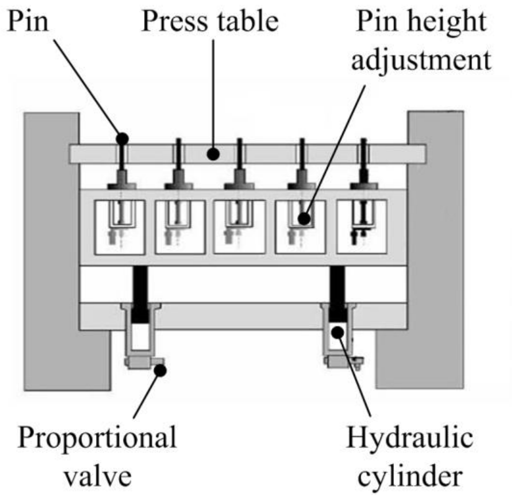


Figure 7; In-die multi-point cushion system height adjustable electro-mechanical pins [Siegert et al., 2000]

[Rittmeier, 2007, Siegert et al., 2000] introduced cushion systems with height adjustable actuators underneath the blank holder. This design also allows the manipulation of the BHF distribution. The cushion stroke is achieved by the regular die cushion situated in the press table; see Figure 6 and Figure 7.

One of the most successful applications of an MPC system worldwide is deep drawing of stainless steel sinks [Altan et al., 2006b]. The effect of eccentric loading due to the product design on the BHF profile is minimized. The material flow is regulated precisely. High surface quality, especially in the flange area is required, i.e. no visible wrinkles are allowed [Pahl, 1997]. In particular, the flange areas on the long sides tend to wrinkle due to blank holder pressure reduction in this area caused by sheet thickening in the flange corners. The stability of the bridge area is very sensitive; no material can be fed into the cavity from this region. Therefore, the blank holder pressure has to be very high in this area to prevent material flow [Pahl, 1997].

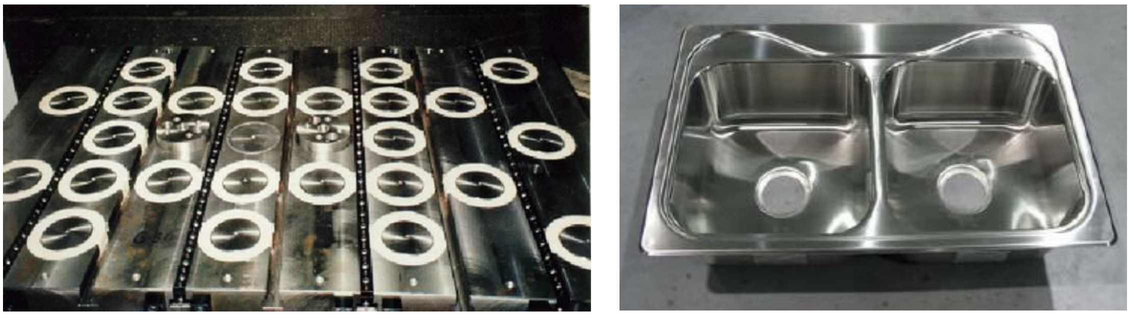


Figure 8; Sample cushion pin configuration for drawing stainless steel double sinks [Dieffenbacher, 2006]

4 CONTROL AND PROGRAMMING OF MPC SYSTEMS

Successful application of multi point cushion systems to form complex parts from low formability material (HSS, Al alloys) requires a methodology to estimate the necessary blank holder force for each cushion pin.

There are four different types of optimal BHF trajectories: A) Current practice is to apply a BHF which is constant in location and constant with stroke. There each cushion pin applies the same force that is kept constant in stroke. Simple single point cushion systems with nitrogen cylinders or hydraulic cylinders are typically used to provide this BHF characteristic. B) The BHF is kept constant in location but varies with stroke. This type of BHF trajectory can be achieved by single point hydraulic or servo mechanical systems. C) In order keep the BHF constant with stroke but vary it in location, MPC systems with hydraulic cylinders, nitrogen cylinders or servo mechanical actuators are required. D) Full controllability of the material flow into the die cavity offers a BHF, which is variable in location and with stroke. Modern MPC units with hydraulic cylinders or servo mechanical drives make this BHF characteristic available.

The estimation of optimum blank holder force for multipoint cushion systems in sheet metal forming could be formulated as an optimization problem with blank holder force as design variable while the objective is to minimize the risk of failure by tearing. The constraints are the wrinkles in the formed part that need to be avoided. This optimization problem cannot be solved analytically. ERC/NSM as part of USCAR project developed an optimization methodology coupled with commercial FE codes to estimate the BHF for individually programmable cylinders in MPC systems [Altan et al, 2006a]. The objective function and the constraint functions required for the optimization were calculated from the results of the FE simulation of the forming process, see Figure 9.

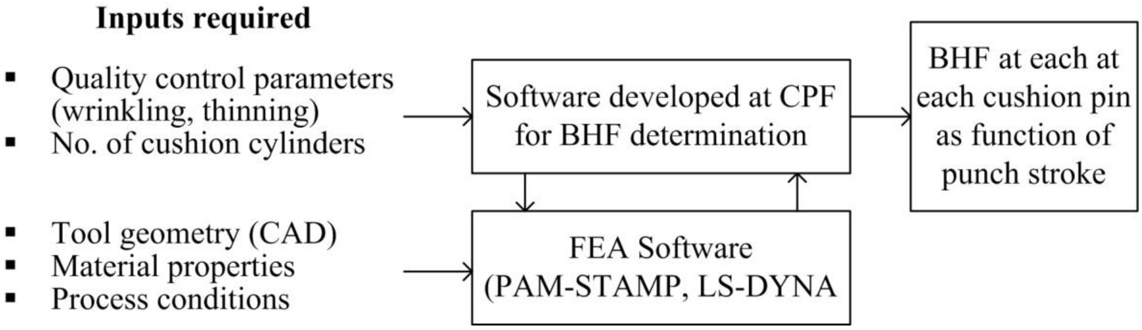


Figure 9; Control strategy to predict blank holder force trajectory for each cushion pin [Palaniswamy, et al, 2006]

As part of USCAR’s project, the blank holder force optimization has been conducted for a large automotive panel. The process was simulated by means of FEA. The inner and outer blank holder were modeled as elastic bodies, see Figure 10. An optimal BHF for each cushion pin was predicted and was successfully applied to the real world part made from aluminum alloy A6111-T4.

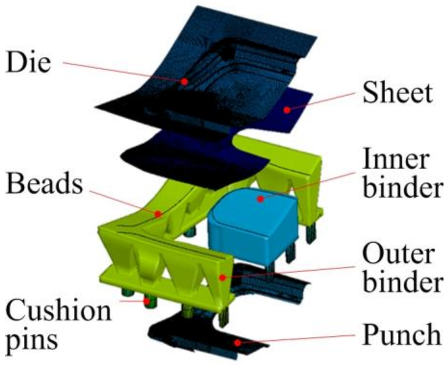


Figure 10; FE model with elastic BH [Altan et al., 2006]

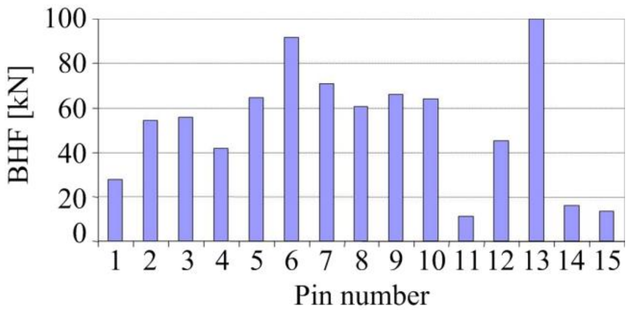


Figure 11; Individual pin forces determined by optimization method [Altan et al., 2006]

Using a hydraulic MPC system installed in mechanical press, the automotive panel was formed successfully - with three different materials/sheet thicknesses in the same die - by only modifying BHF in individual cushion pins, see Figure 12.

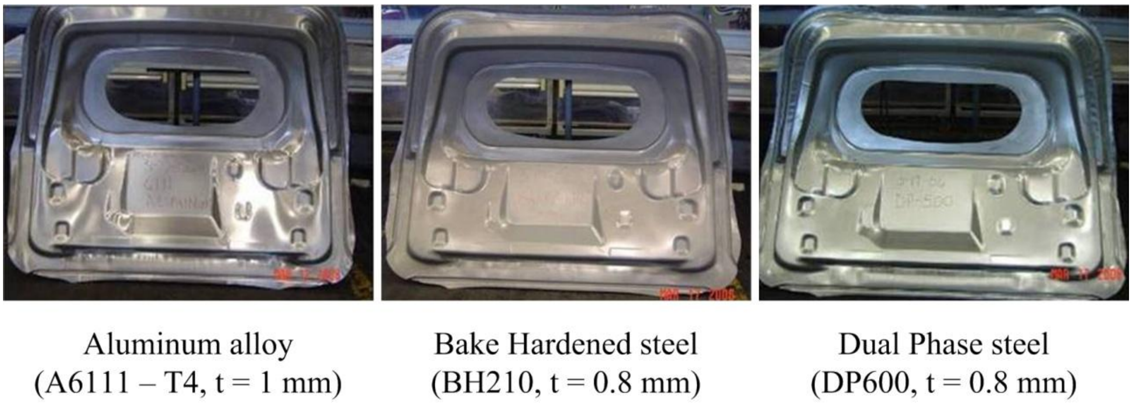


Figure 12; Automotive panel from different materials produced in the same tool by varying BHF profile

Various other studies were carried out in order to validate the optimization methodology. Optimization techniques developed as part of the USCAR project on flexible binder force control were modified and adapted for the SHF-P process, in cooperation with IUL-Dortmund. A similar study was conducted at the ERC/NSM using an automotive part, see Figure 13. The sequential optimization was used to predict BHF versus stroke and pot pressure versus stroke. In a cooperative study, between ERC/NSM and IWU-Chemnitz, the optimum BHF variable in location was predicted for a stamping operation, see Figure 14.

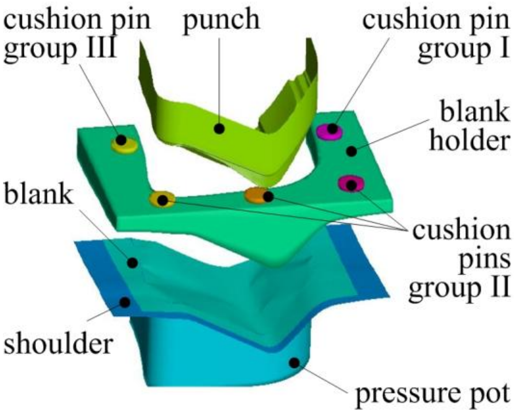


Figure 13; Sheet hydroforming with punch

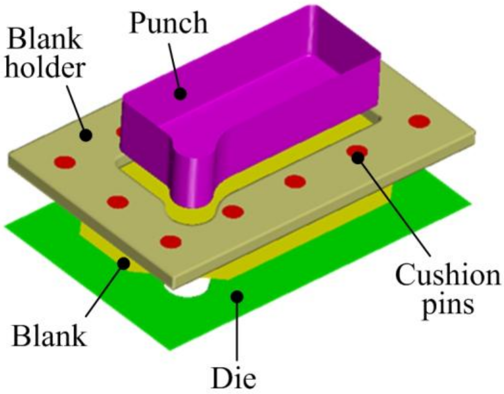


Figure 14; Stamping [in corporation with IWU Chemnitz]

5 CLOSED LOOP MPC CONTROL

The capability of multi-point cushion systems is underutilized in today's production because a) it is complex to predict an optimal BHF trajectory for each cushion cylinder and b) conventional steel sheets can be formed with existing method of constant blank holder force [Altan et al., 2006]. Even with predicted optimum BHF, there can be inconsistency in metal flow in production. This inconsistency can be attributed to the variations in:

- Sheet material properties (variations in incoming coil/different supplier) and/or,
- Process conditions such as lubricant behavior (smearing), tool temperatures, etc.

One possible solution would be an in-process closed loop control, which requires sensors to measure a control variable. Different approaches and sensors were introduced to measure material draw-in, wrinkle height or friction force [Siegert et al, 2000]. In general, these sensors are susceptible to failure in the rough manufacturing environment. As a result, press operators ask for robust and maintenance free systems to be integrated in the process control. It seems that utilizing the material draw-in as a control variable could deliver the best results regarding process control. Therefore, a simple methodology, with no need for additional sensors is needed to modify/adjust the BHF in individual cushion cylinders during production.

It is proposed to compare digitally the draw-in (flange outline) of the produced part with the draw-in (flange outline) for a good part (estimated by FEA) [Schnupp, 2006]. Figure 15 shows the position of the example cushion cylinders and the flange outline of both a produced part and predetermined good part. The suggested methodology proposes to stamp the part with the optimum BHF predicted by tool try-outs or by FE simulation.

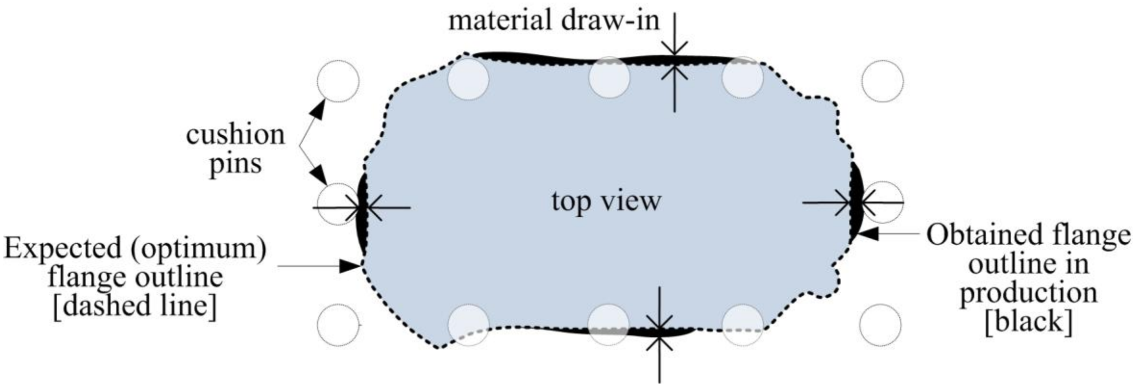


Figure 15; Mismatched draw-in (flange outlines) seen in top view for a sample part, in a proposed digital visualization system

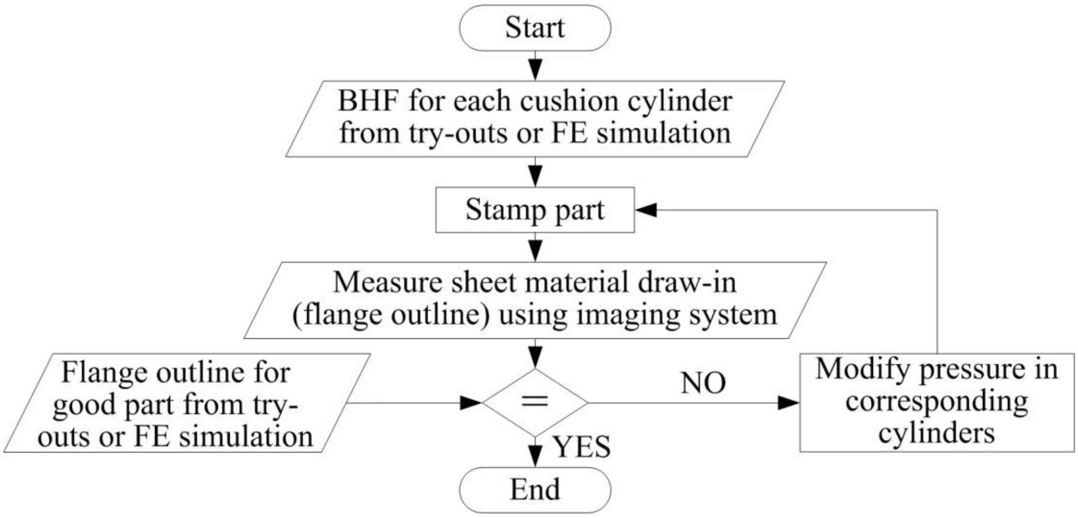


Figure 16; Flow chart for blank holder force optimization for each cushion cylinder during process

In order to obtain a feedback after forming the flange outline is measured by an imaging system. Subsequently, the flange outline of the formed part and the flange outline for the ideal part are compared. In case the flange outlines match within certain tolerances, the part can be produced with the present BHF. If not, the corresponding cylinder forces have to be adjusted until the two flange outlines match within the tolerances, see Figure 16.

6 CONCLUSION

Using the proposed methodology would eliminate the need for additional sensors in the tooling and would therefore reduce investment costs and increase the robustness of the process and the process control.

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