Electrohydraulic Forming of Light Weight Automotive Panels

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Abstract

This paper describes the results of development of the electrohydraulic forming (EHF) process as a near-net shape automotive panel manufacturing technology. EHF is an electro-dynamic process based upon high-voltage discharge of capacitors between two electrodes positioned in a fluid-filled chamber. This process is extremely fast, uses lower-cost single-sided tooling, and potentially derives significantly increased formability from many sheet metal materials due to the elevated strain rate. Major results obtained during this study include: developing numerical model of the EHF; demonstrating increased formability for high-strength materials and other technical benefits of using EHF; developing the electrode design suitable for high volume production conditions; understanding the limitations on loads on the die in pulsed forming conditions; developing an automated fully computer controlled and robust EHF cell; demonstration of electrohydraulic springback calibration and electrohydraulic trimming of stamped panels; full scale demonstration of a hybrid conventional and EHF forming process for automotive dash panel.

Keywords

Electrohydraulic forming, High voltage discharge, Automotive panels

1 Introduction

According to the general trend of decreasing vehicle weight, advanced high strength steels (AHSS) and aluminum alloys (AA) are being used more and more in automotive body construction. In order to achieve formability levels offered by mild steels and bakehardenable steels, further development is necessary in sheet metal forming technologies. Electrohydraulic forming (EHF) is capable of achieving such improvements for both AHSS and AA. EHF also offers significant reducing in tool cost because only a one-sided die is required. Compared to popular electromagnetic forming processes, EHF does not impose any special requirements to electrical conductivity of the deformed material or necessity to be positioned close to the coil. EHF also allows several pulses to be produced in one tool without necessity to use several coils and several sets of dies.

In EHF, an electrical energy, stored in a high-voltage capacitor, is discharged across a gap in water enclosed in a discharge chamber. A small volume of liquid between the tips of the electrodes is vaporized and then forms a plasma channel. Electrical current continues to go through the channel thus converting the electrical energy into the internal energy of plasma bubble, which happens over a very short period of time, usually less than 100 microseconds. This leads to explosive expansion of the channel with forming high velocity shock waves in the liquid, which form a blank into a die.

EHF technology was developed in early 50-s mostly as a method of producing low volume parts at low cost. Yutkin (1955), Bruno (1968), and Davies and Austin (1970) reviewed early applications and research results on EHF. A significant advantage of EHF compared to traditional sheet metal forming technology is that it does not require two matching dies: a punch is usually replaced by the liquid transmitting pressure from the discharge channel to the surface of the blank. Bruno (1968) described a number of industrial examples where EHF machines storing 36kJ, 60kJ, 150kJ and 172kJ were employed. However, due to the necessity to fill the chamber with liquid at the beginning of each forming cycle and evacuate the liquid at the end of it, the cycle time for EHF was in the range of several minutes. Sanford (1969) described a hybrid technology where static hydroforming was used to bulge sheet metal into the die cavity followed by EHF which provided higher pressure level and filled the details of the die cavity. According to Sanford (1969), a typical cycle time for such a hybrid process is 10 minutes.

More recently, Balanethiram and Daehn (1994) reported increased forming limits after forming into a conical die compared to Forming Limit Diagrams of copper and AA6061-T4: the maximum strain for plane strain conditions was increased factor of 2.5 for copper and factor of 5 for AA6061-T4. Significant improvements in formability of AA 6111-T4 (approximately factor of 2.5), 5754 and 5182 (approximately factor of 3) after formation into conical dies and elongated corner die (V-shape) using electromagnetic forming technology were reported by Imbert et al (2005) and Golovashchenko (2007).

Very limited attempts have been made to simulate the EHF process. Golovashchenko and Mamutov (2005) presented results of bulging into an open round die. Vohnut et al (2010) reported results of pulsed loading in closed volume assuming energy equivalence to the explosive forming.

The objective of the research project reported in this paper is to develop EHF process as a near-net shape automotive panel manufacturing technology suitable for mid volume production of full-scale parts.

2 Developing Numerical Model

Numerical modeling is crucial for designing an optimal technological process in reasonable time. During work on the project, significant progress was made in developing a numerical model of the EHF process. The developed multiphysics numerical approach includes expanding discharge channel, compressible liquid as a pressure transmitting medium, deformable blank which interact with a rigid die. Each individual model was developed using the capabilities of LS-DYNA commercial code.

The plasma channel was modelled in LS-DYNA as an adiabatically expanding bubble of ideal gas. The electric energy is assumed to be introduced uniformly through the channel volume. The energy deposited in the channel was obtained experimentally for the specific configuration by measuring electrical current and voltage during discharge. The liquid was assumed ideally compressible. Modelling of sheet metal blank formation into a designated shape was conducted using an elastic-plastic shell. To eliminate the issue of mesh distortion, the Arbitrary Lagrange Eulerian (ALE) solver with Multi-Material capability available in LS-DYNA was employed. The details of the developed numerical approach are described in (Mamutov et al, 2015).

Simulation of full process chain of multistage EHF of the license plate area of a decklid has been performed. The chamber and the one-sided die are shown in **Fig.1**.

The evolution of the shape of the discharge channel and deformation of the blank during the first EHF stage are shown in **Fig.2**. Progress of blank formation after each discharge is illustrated in **Fig.3**.

3 Enablers of EHF Technology

The formability of AHSS in pulsed forming conditions was investigated experimentally and also using numerical simulation. The results show that significant improvements in formability is observed for DP780 and DP980 when forming into conical and v-shape dies using EHF from a flat sheet. The observable failure modes are in good correlation with the results of numerical simulation. The results of these researches are explained in details in (Gillard et al, 2013) and also in (Golovashchenko et al, 2014c).

A series of tests on electrodes were conducted to study the viability of Electro-Hydraulic Forming for production applications. As a result, the recommendation on electrodes material and design were obtained which is explained in details in (Bonnen et al, 2013).

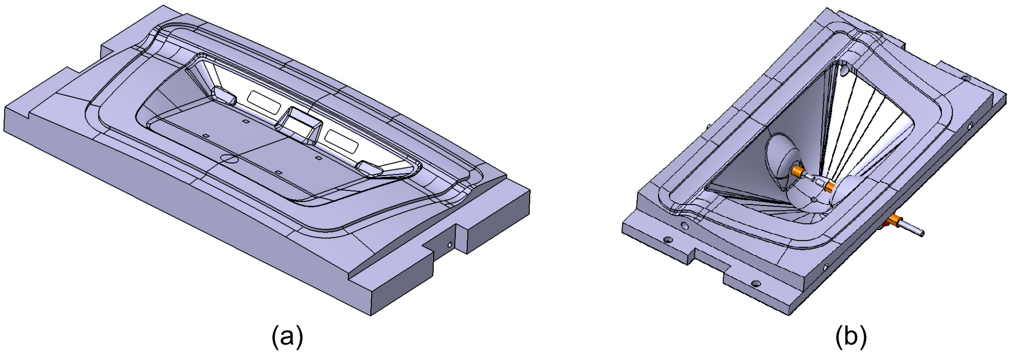


***Figure 1**: Geometry of the die (a) and the chamber (b)*

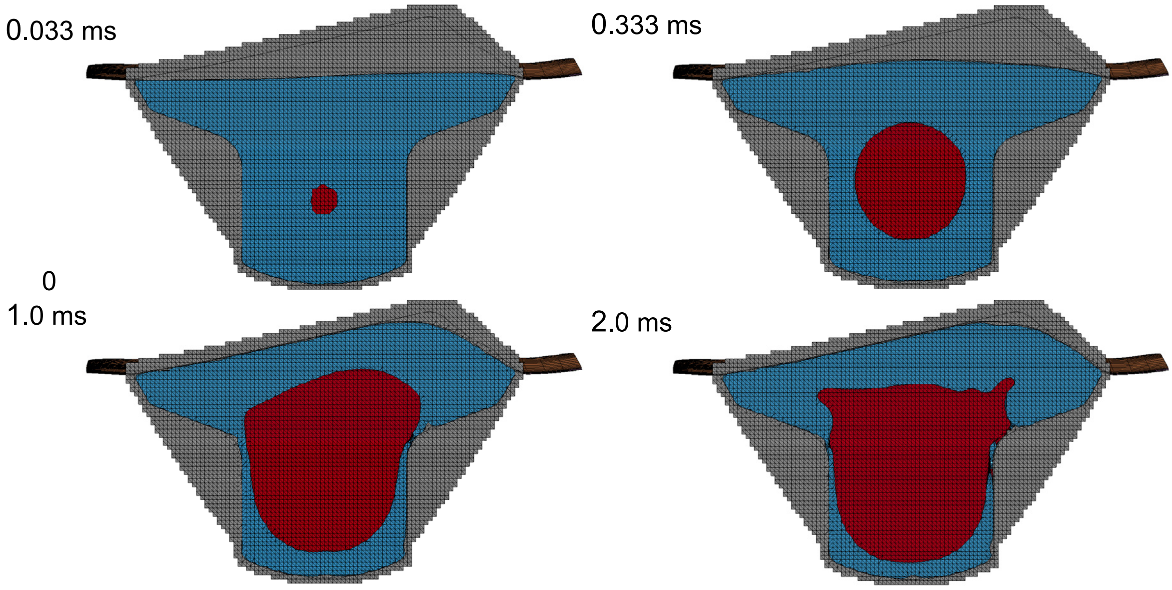


***Figure 2**: Channel expansion and deformation of the blank during the first discharge*

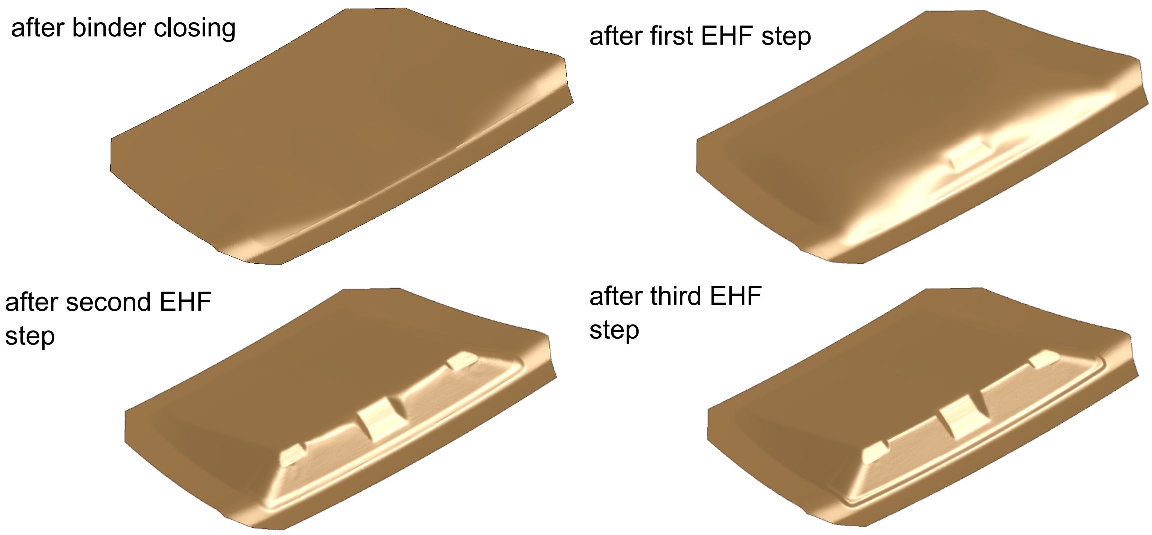


***Figure 3**: Changing of blank geometry*

The extensive research was performed regarding correct simulation of impact behavior which is crucial for the robust die tooling design. As a result, the recommendation on choosing the contact algorithm were obtained and verified experimentally. The results are described in details in (Ibrahim et al, 2014).

With appropriate discharge energy that ensures filling all the die features, the final shape of a blank, formed by EHF, matches the die. The factor that is affecting the final shape is the springback. EH calibration, the operation which is similar to a conventional restrike operation, except that the pressures are much higher, was demonstrated as an efficient method to reduce springback in the formed parts comparing with the conventional forming. The results are published in (Golovashchenko et al, 2014b).

Another demonstrated extension of EH technology was the EH trimming which enables trimming operations without a punch and also significantly reduces formation of a bur in comparison with conventional trimming methods. The results are published in (Golovashchenko et al, 2014a). The additional research on cutting edge loads during EH trimming is published in (Tang et al, 2014).

4 Demonstration of EHF Automation Cell

The fully automated cell was created to demonstrate the possibility to use EHF at production rates. Multiple tasks were completed to overcome different challenges, to increase robustness, and decrease the cycle time. The major task, which required several iterations during the overall development, was to integrate all the components (the gantry, hydroforming, electric pulse generator, safety system, vacuum pump, hydraulic press, and water/air management system) into an automated system and to establishing remote control via the Ethernet and feedback using variety of sensors. The humidity rising during continuous operation increases the risk of an unplanned internal arc or discharge. Solving this issue required reorganization the components in space, establishing proper ventilation and using a commercial de-humidifier. The electrical isolation and grounding of the electric pulse generator was improved to increase robustness and electrical safety. Filling the chamber with water and water draining after discharges is the major factor that slows down the productivity of EHF. To solve this issue, the custom Fluid Handling Systems (FHS) was designed, manufactured, and built into the cell. The new FHS increased the fluid drain and fill rates over an order of magnitude from 26 to 380 liters/min. FHS also integrates the high pressure functionality to increase the production rate of both EHF and hybrid forming of EHF combined with traditional sheet hydroforming. The increased fluid drain had required optimization of the size of the water/air ports going into the chamber/die. Experiments and numerical simulation were performed to find the optimal ports size that does not constrict the flow too much and, at the same time, does not reduce efficiency of the process. The chamber diaphragm was introduced to ensure that clean fluid was always in contact with the blank and to ensure that any fluid contaminated with electrode erosion products was confined to the region around the electrodes.

The part used for demonstration and the automated cell are shown in **Fig.4**.

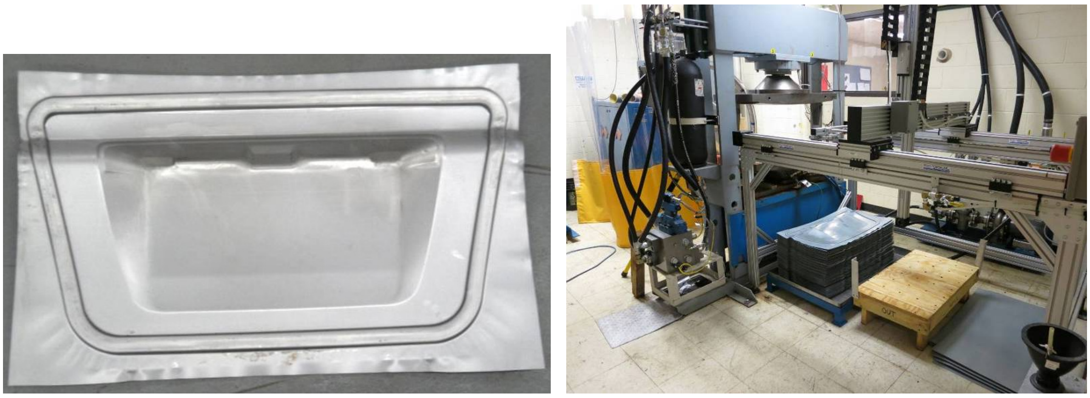


***Figure 4**: License plate and automated cell for its production*

Operation of the EHF cell includes the following steps: 1) the gantry retrieves the blank from sheet metal stack; 2) the gantry places the blank on the blank holder surface located between the die and the EHF chamber; 3) the press is closed, and the lock beads clamped the blank; 4) the chamber is filled with water; vacuum is drawn on the die preventing potential air pockets between the blank and the die surface; EHF pulses are applied; 5) water is drained down, and vacuum is released; 6) fully formed part is picked up by the gantry and moved to the stack of stamped parts. There were four discharges applied for each part with increasing voltage up to 12 kV (14.4 kJ) for the last calibrating discharge which ensured filling all the radii and repeatable resulting parts' shape matching the die geometry.

The EHF cell was able to produce over 100 parts formed in two batches over a total running time of approximately 3 hours. It was capable of running an 8 hour shift without maintenance. Further details can be found in report (Golovaschenko, 2013).

5 Full Scale Demonstration of a Hybrid Conventional and EH Forming Process for Automotive Dash Panel

The fabrication of tooling for the full-scale demonstration of the dash panel (**Fig.5**) forming process was the major effort of the project. This part imposes significant formability challenges because it has very deep and wrinkling prone central area and can be produced only from mild steel when using a conventional stamping approach.

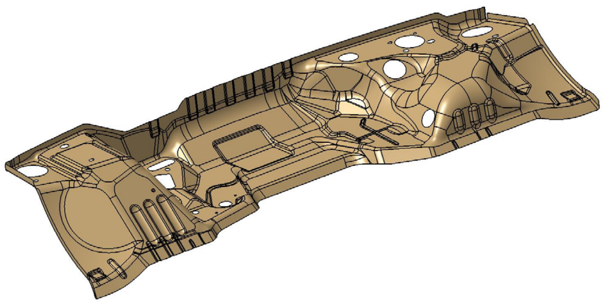


***Figure 5**: Geometry of the dash panel after trimming and flanging*

The tool set included the following dies: the preforming die and the final shape die for EHF forming. The preforming die was designed and fabricated as a triple action tool schematically shown in **Fig.6**.

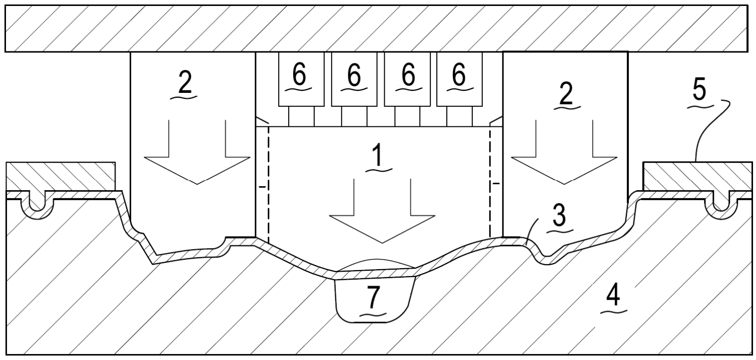


***Figure 6**: Geometry of the dash panel after trimming and flanging*

The approach (patented, Golovashchenko et al 2015) is that the central punch 1 was fabricated separately from the side punches 2. At the beginning of the process, the flat blank 3 is positioned inside the tool on top of the lower preforming die 4 using guiding pins. After closing the binder 5 and clamping the periphery of the part, the central punch backed by cylinders 6 (which may be hydraulic, pneumatic or nitrogen) starts drawing the blank in the central region of the part. Once the central punch reaches its home position, the upper die continues to travel downward, allowing the side punches to form the rest of the panel while the central punch is held in its position by the cylinders. After the side punches complete their stroke, the press stops and dwells with all punches in the home position. Water is then pumped into the metal gainer pocket 7 region to reverse form the pocket (which can be also performed as an EHF operation). The components of the preforming die are shown in **Fig.7**.

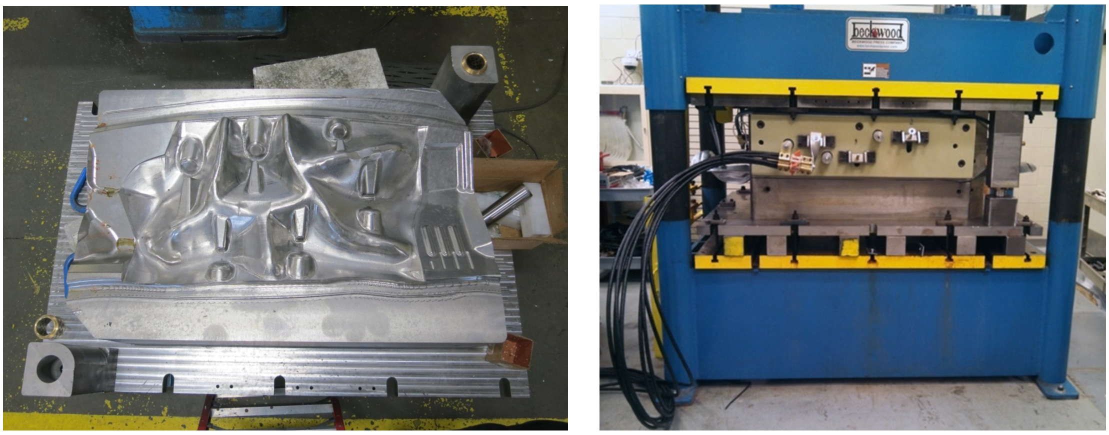
a) b)

***Figure 7**: Assembled upper (a) and lower (b) preforming dies*

The shape of the blank after finishing the preform operation is shown in **Fig.8**.

***Figure 8**: Preformed blank*

The EHF tooling includes the die and the multielectrode chamber shown in **Fig.9a**. **Fig.9b** shows the EHF chamber and die assembly installed in a 150 ton hydraulic Beckwood press. The sequence of steps for the final forming stage using EHF was the following: the partially formed part is placed in the die and located by two guide pins; the chamber and die are closed; the chamber is filled with fluid; each of the electrodes in each subchamber is pulsed sequentially.



a) b)

***Figure 9**: EHF chamber prior to the installation of electrodes (a) and EHF tooling in closed position during the tryout process (b)*

The final shape of the dash panel after finishing EHF step is shown in **Fig.10**.

***Figure 10**: The fully formed dash panel (1.5 mm DP600) after EHF forming*

6 Conclusions

As a result of the performed study, important enablers have been developed advancing the EHF technology as a method of producing near-net shape automotive panels of AHSS. That includes:

1. Reducing of the cycle time due to the development of the water/air management system; extension of the electrode life and minimizing of the electrode system maintenance based on electrode erosion study. This made possible to create a fully automated and robust production cell with suitable for industrial production.
2. Developing a complete simulation tool based on LS-DYNA code which enables simulation-driven design of the EHF tooling.
3. Detailed study on contact algorithms used in FEM which enables precise simulation of impact loadings and correct choosing the appropriate tools materials during design.
4. Extensive study on material formability which confirms benefits of using EHF to improve formability of AHSS over conventional stamping.
5. The possibility to perform calibration to reduce springback and to perform trimming operation was demonstrated.
6. The full-scale demonstration of the dash panel forming process using combined conventional-EHF process was performed to demonstrate the maturity of the technology.

Acknowledgments

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