

# An Experimental Study: Improved Electrohydraulic Forming Efficiency through Wire-Free Discharge

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## Abstract

*This experimental research proposes improved electrohydraulic forming (EHF) methods to overcome the limitations of traditional high-speed forming and deep-drawing processes. EHF uses a working fluid to generate forming force, which lasts longer than in electromagnetic or explosive forming, allowing precise shape control. However, conventional EHF requires fastening wires and draining/refilling the working fluid for each experiment, resulting in long preparation times and inconsistent forming due to variation in wire position. To address these issues, two new methods 'wire-cross EHF' and 'wire-free EHF' were introduced and tested using a free-bulging die and 0.5 t STS430 specimens. Forming distribution was analysed by comparing forming force, forming height, and preparation time. The wire-free EHF showed lower initial forming force but achieved comparable forming height through consecutive experiments. It also demonstrated high consistency and reduced total experiment time by 4.72 times compared to the conventional EHF, which suffered from increased wire length during twisting, leading to variations in forming height and forming distribution. Overall, the wire-free EHF proved most effective in achieving consistent forming results with significantly reduced preparation time, making it a promising approach for efficient EHF process.*

## Keywords

Free forming, Hydroforming, Electrode

## 1 Introduction

In response to increasingly stringent environmental regulations, the transportation industry- including automobiles and aircraft- has been focusing on improving fuel efficiency by reducing vehicle weight [1]. To form the outer body panels of such vehicles, the deep-drawing method using presses and dies is widely applied. However, when using materials such as aluminium alloys or high-strength steels, the formability is relatively low, often resulting in discrepancies between the intended and actual formed shapes due to elastic recovery. Various studies are underway to address this issue [2].

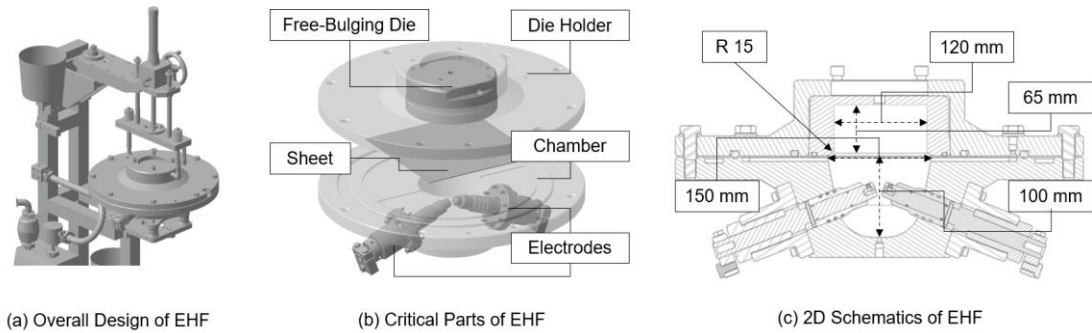
EHF, a high-speed forming technique, has emerged as a promising alternative to enhance forming distribution in sheet metal processing [3]. The rapid forming speed generates compressive stresses that suppress void growth during deformation, thereby improving the material's extension capacity. Furthermore, unlike other high-speed forming methods, EHF utilizes hydraulic pressure as a medium, enabling a longer application of forming force. This extended pressure reduces spring back effect, improving forming accuracy. Despite these advantages, EHF has not been widely adopted in the manufacturing industry due to time-consuming preparation and relatively high costs.

This research explores two novel EHF approaches aimed at reducing experimental preparation time while maintaining consistent forming distribution. Specifically, two modified experimental setups – a wire-free configuration and a simplified wire-cross configuration – were tested and compared using 0.5 t STS430 rectangular sheets and a free-bulging die. In both methods, the discharge voltage was fixed at 6 kV. As the wire-free setup tends to generate lower forming force in a single discharge, a consecutive discharge approach was employed to achieve a comparable bulging height. The number of discharges and total time required to reach equivalent forming results were evaluated using 3D scanning results of formed specimens.

## 2 Experimental Setup

### 2.1 Conventional Electrohydraulic Forming (Using single wire)

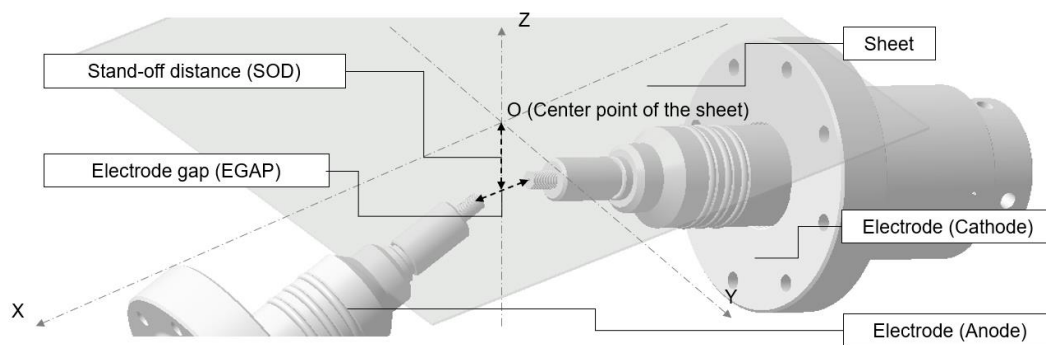
EHF used in this research is illustrated in Fig. 1. It comprises a die, a chamber set capable of draining and refilling working fluid, and a sheet positioned between them. The die is designed with a hole within the holder region that secures the sheet, allowing for the installation of various shapes of die configurations. In this research, a free-bulging die was employed. The die has a cylindrical shape with a diameter of 120 mm and a height of 65 mm. The radius at the sheet inlet region is 15 mm. The chamber contains a pair of electrodes through which electric energy, stored in a capacitor, is discharged. It has a rounded conical shape in its side profile, with a maximum depth of 100 mm measured from the sheet. Its diameter is 150 mm, determined based on the inlet region of the die. The sheet used in the experiments was a rectangular STS430 specimen with a length of 460 mm, a width of 230 mm and a thickness of 0.5 mm.



**Figure 1:** Apparatus of electrohydraulic forming device

In the conventional setup, a thin wire is connected between the electrodes. When the capacitor discharges, a high current flows instantaneously through the wire, ideally concentrating the electrical energy at its center. This causes the wire to explode, and the resulting high-pressure shockwave transmits forming force through the working fluid to the sheet.

The magnitude of the forming force is primarily determined by the capacitor specifications and the input voltage. However, the location of the wire also influences the effectiveness of the forming process. As shown in Fig. 2, under identical conditions (input voltage, capacitor capacity, wire material, and length), two key variables, stand-off distance (SOD) and electrode gap (EGAP) significantly affect the forming force. Experimental results confirmed that the maximum forming force in the conventional configuration is achieved at an EGAP of 20 mm and SOD of 35 mm.



**Figure 2:** Definition of variables of electrohydraulic forming force

## 2.2 Proposed Electrohydraulic Forming Methods

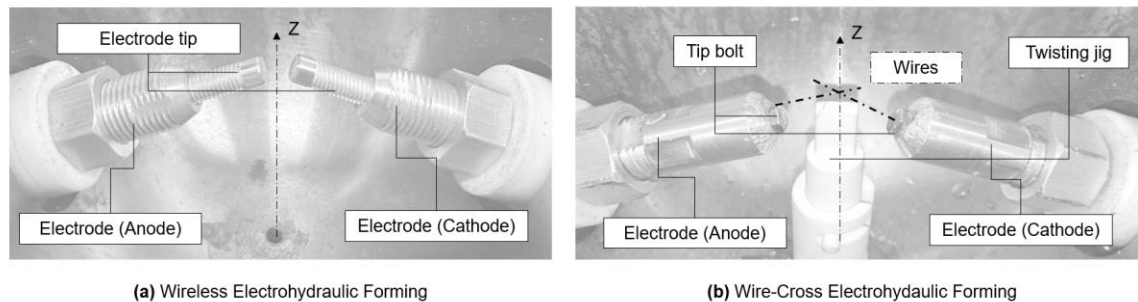
To address the time-consuming nature of wire installation in conventional EHF, this research proposes two alternative methods. The first is a wire-free method, which eliminates the wire entirely by placing two electrode tips at a narrow gap. The second is a wire-cross method, where two short wire segments are connected to each electrode in a crossing configuration.

The wire-free method was inspired by in-house experimental observations which showed that electrical conduction can occur across a short gap under high-voltage discharge.

This method is like the EDM (electric discharge machining), which processes the surface of a material using electrical discharge. The wire-cross method, on the other hand, is based on the idea that a wire can fully vaporize into plasma before generating the forming force.

As illustrated in Fig. 3, the wire-free method can significantly reduce preparation time by removing the need to install wires between experiments. Meanwhile, the wire-cross method, although still requiring wire installation, allows faster and more consistent setup compared to the conventional method. Furthermore, it can generate forming forces comparable to those of the conventional setup due to the closed-circuit configuration.

To determine which of the three methods, conventional, wire-free, or wire-cross EHF is the most time-efficient, experiments were conducted to establish the optimal forming conditions that produce the maximum forming force in each case. With the input voltage fixed at 6 kV, suitable SOD and EGAP values were experimentally identified.



**Figure 3:** Two proposed electrohydraulic forming methods

### 2.3 Pre-Experiment for Maximum Forming Force

The wire-cross method utilizes the same wire material and length as the conventional case and thus adopts the same SOD and EGAP values. However, in the wire-free method, the electrode tips have a larger cross-sectional area to prevent electrode damage during consecutive discharges. Therefore, a separate experiment was conducted to determine the optimal electrode positioning for maximum forming force in the wire-free configuration.

Due to the 20-degree incline of the electrodes in the owned EHF device, SOD and EGAP are geometrically linked. Five experimental cases were designed by varying EGAP to investigate its effect on the bulging height and electrode wear in the wire-free method. The formed sheet's bulging height and electrode tip wear were measured accordingly.

As shown in Fig. 4, an EGAP of 7 mm yielded the highest bulging height, and was thus selected for the wire-free configuration. The results show that as EGAP increases, electrode wear decreases and bulging height increases. This is attributed to the reduced arc concentration at the electrode tip, leading to less electrode wear, and the more favorable formation and propagation of the pressure wave with increased EGAP. However, beyond an EGAP of 9 mm, bulging height begins to decrease, and electrode wear increases again. At EGAP 11 mm, no forming force was observed due to the failure of electric discharge in the open circuit, indicating a limit in electrical energy transfer from the capacitor to the working

fluid. It's because if the EGAP is too large, the discharge energy dissipates within the working fluid before reaching the sheet.

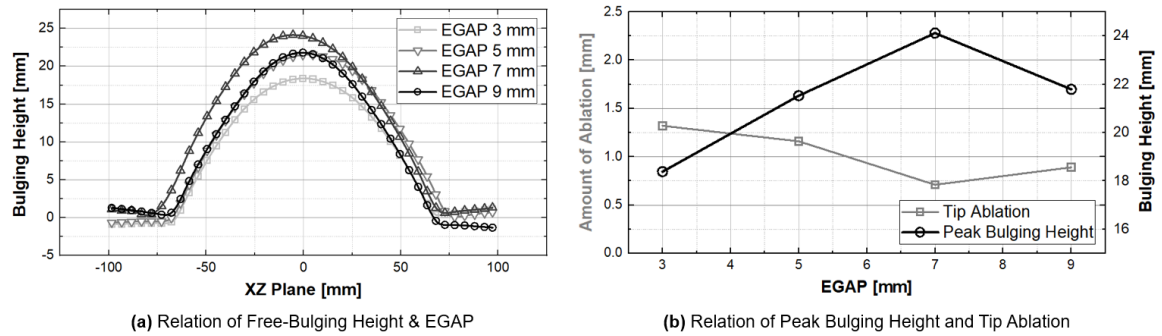


Figure 4: Relation among EGAP, amount of tip ablation and free-bulging height

### 3 Experimental Results

#### 3.1 Comparison of Free-Bulging Height

Three experiments were conducted for each forming method, conventional, wire-free and wire-cross using 0.5 mm thick STS430 rectangular specimens. The bulging results were captured via 3D scanning along the plane parallel to the current flow direction. In the wire-free case, up to three consecutive discharges were applied to achieve bulging heights comparable to the wire-based methods under the same voltage input. These consecutive discharges were conducted without draining and refilling the working fluid and without separating the die and chamber. To maintain a constant EGAP, the electrode was moved forward during successive discharges, compensating for the ablation observed in Section 2.3.

Fig. 5 presents the forming results for the conventional and wire-cross EHF. Fig. 6 shows the results of one-time and two-time consecutive discharges repeated three times each for the wire-free method. The results of three-time consecutive discharges were excluded from Fig. 6 as they exceeded the forming heights obtained from the wire-based methods under the same voltage. The peak heights of each test are summarized in Table. 1

For a single discharge, the conventional method produced an average bulging height of 26.99 mm, while the wire-cross method achieved a higher average of 30.12 mm. The wire-free method yielded 23.11 mm with a single discharge, 29.81 mm with two discharges, and 32.09 mm with three discharges. These results indicate that the wire-cross EHF outperforms the conventional EHF in terms of forming height, likely due to the increased wire length in the crossed-wire configuration, which generates greater explosive energy compared to the tightly fixed wire in the conventional setup.

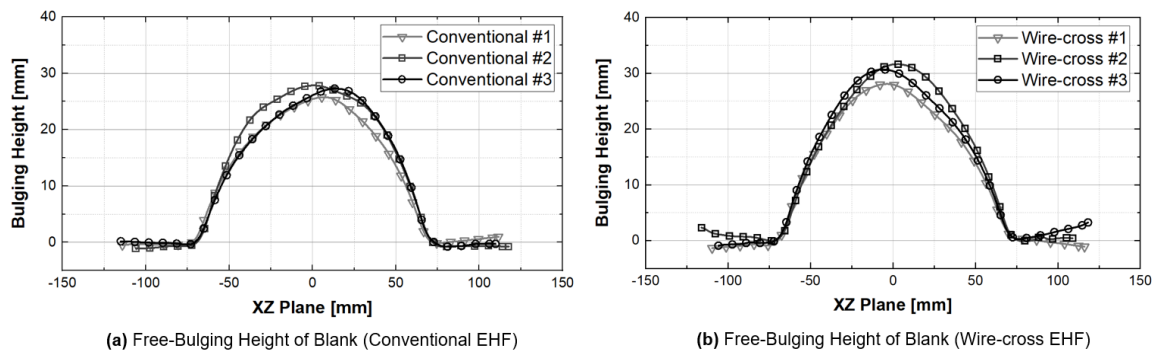
In contrast, the single-discharge performance of the wire-free EHF was lower due to its open-circuit configuration. However, by applying consecutive discharges, the forming height increased progressively by 6.7 mm in the second discharge and by 2.28 mm in the third, demonstrating the method's cumulative forming effect. This reduction in incremental

height is due to the increase in SOD with each discharge, which causes greater energy loss as the shockwave travels farther through the working fluid before reaching the sheet.

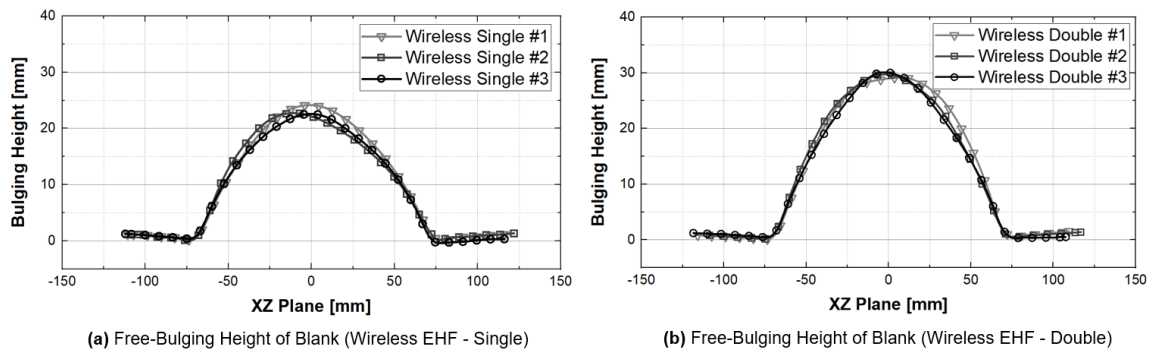
Moreover, the wire-free EHF exhibited more consistent forming distribution across repeated trials. In wire-based method precise central positioning of the wire is difficult to achieve manually, often resulting in off-centered bulging peaks. In the wire-free case, the peak consistently formed at or near the center of the chamber-die assembly and shifted closer to the center with each consecutive discharge, confirming improved uniformity.

| Experiment | Conventional | Wire-cross | Wire-free #1 | Wire-free #2 | Wire-free #3 |
|------------|--------------|------------|--------------|--------------|--------------|
| No. 1      | 25.77        | 28.01      | 24.12        | 29.48        | 31.70        |
| No. 2      | 27.87        | 31.66      | 22.64        | 29.74        | 32.50        |
| No. 3      | 27.34        | 30.66      | 22.58        | 30.18        | 32.08        |

**Table 1:** Maximum bulging height for each experimental method [mm]



**Figure 5:** Experimental results with wire-using electrohydraulic forming



**Figure 6:** Experimental results with wire-free electrohydraulic forming

### 3.2 Comparison of Experimental Time

Fig. 7 illustrates the overall process flow and time required for each experimental method. While routine equipment maintenance, such as electrode tip replacement took minimal time, a significant portion of the time in wire-based methods was consumed in the wire installation. Accurately placing and tensioning the wire across the chamber’s center with consistent

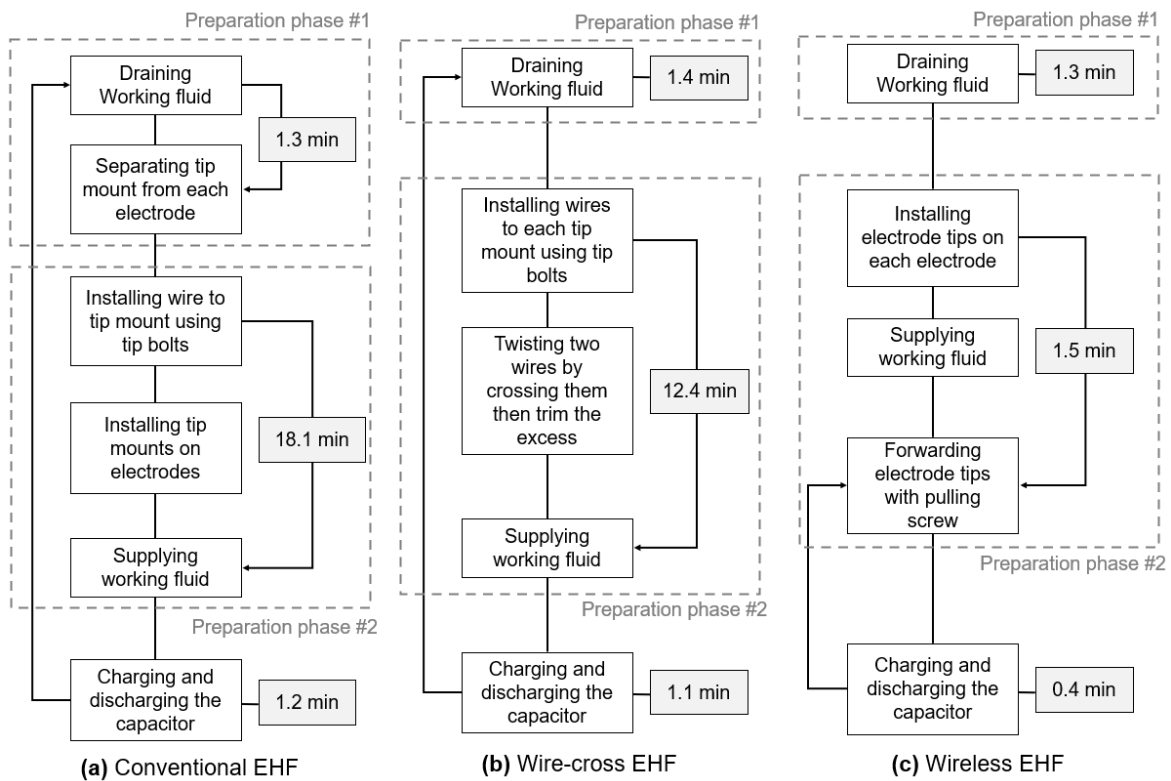
length was especially time intensive. Although the wire-cross method offers more flexibility in wire length, it still required 12.06 times more preparation time than the wire-free method.

In contrast, the wire-free method drastically reduced time requirements by eliminating the need to install wires or replace the working fluid between discharges. After each test, only the electrode needed to be adjusted to maintain the constant EGAP. Table 2 summarizes the time required for each method: 20.6 minutes for a single experiment in the conventional EHF, 14.9 minutes for the wire-cross EHF, and just 3.2 minutes for the wire-free EHF. For consecutive experiments, the time difference becomes even more significant. The conventional and wire-cross EHF must repeat all process steps, including wire installation and fluid replacement, while the wire-free method only requires capacitor recharging and electrode adjustment. Consequently, the second wire-free discharge takes only 0.4 minutes.

These results demonstrate that the wire-free method can reduce experimental time by up to 98% compared to the conventional method and 97% compared to the wire-cross method. Furthermore, the time savings increase proportionally with the number of tests confirming the efficiency and practicality of the proposed wire-free electrohydraulic forming approach.

| Method | Conventional | Wire-cross | Wire-free #1 | Wire-free #2 | Wire-free #3 |
|--------|--------------|------------|--------------|--------------|--------------|
| Time   | 20.6         | 14.9       | 3.2          | 3.6          | 4.0          |

**Table 2:** Time required for each experimental method [min]



**Figure 7:** Working flow charts and time required for each experimental method

## 4 Summary

This study focused on addressing the inefficiencies of conventional electrohydraulic forming (EHF), a high-speed forming technique that offers several advantages over the traditional deep-drawing method. In particular, the focus was on reducing the overall processing time by minimizing wire installation, which is one of the most time-consuming steps in EHF.

To tackle this issue, two alternative methods: wire-cross and wire-free EHF were proposed and experimentally evaluated. Both approaches aimed to resolve the inefficiencies inherent in the conventional experiment. Among the three methods tested under identical input voltage conditions, the wire-cross method produced the highest bulging height. However, both wire-based methods demonstrated inconsistency in forming results when wires were not precisely fastened, and accurate installation remained a time-intensive process.

In contrast, the wire-free method, while yielding the lowest forming height in a single experiment, significantly reduced the experimental time. Furthermore, by applying consecutive discharges, the wire-free approach was able to achieve bulging heights comparable to those of the wire-based methods. Despite requiring multiple discharges, the total time remained substantially shorter, highlighting the wire-free methods' potential as more efficient and reliable alternative for electrohydraulic forming.

### 4.1 Acknowledgments

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