RESEARCH ON IMPROVING THE BENDING MACHINE FOR THE TRUCK FRONT BULL BAR

Doan Van Nguyen[1], Quyen Tra Kim Nguyen[2], Long Nhut-Phi Nguyen[3]

Faculty of Mechanical Engineering, Ho Chi Minh City University of Technology and Engineering (HCM-UTE), Ho Chi Minh City, Vietnam.

Email: [1]nvdoan@hcmute.edu.vn, [2]quyenntk@hcmute.edu.vn, [3]longnnp@hcmute.edu.vn

Corresponding Author: **Long Nhut-Phi Nguyen**

Abstract

This article suggests enhancing the hydraulic pipe-bending machine by transitioning from manual to semi-automatic and fully automatic modes, tailored for manufacturing truck front bull bars. The control system integrates a PLC, an HMI, sensors, and a CAD file processing application, enabling input of X-Y coordinates or control derived from CAD drawings to achieve precise bending paths and high consistency. The findings indicate improved machining efficiency and a notable reduction in bending errors.

Keywords: Semi-automatic and automatic operation, Truck front bull bar, PLC, HMI, Sensors, CAD

I. Introduction

In modern industrial manufacturing, automation plays a crucial role in boosting productivity, enhancing accuracy, and reducing dependence on skilled labor. Traditional mechanical tools, such as hydraulic pipe benders, are increasingly being automated to meet evolving needs. Automation systems for hydraulic bending machines have been tested and adopted in many advanced industries worldwide. However, the high initial costs of CNC or servo systems pose a challenge for small and medium-sized businesses. Therefore, a practical solution is to develop innovative methods that leverage existing equipment platforms to enable automation cost-effectively.

The [IX] project aimed to develop a hydraulic rod-bending machine with the goals of minimizing manual labor, accelerating the bending process through a hydraulic system and positioning mechanism, and enabling die-size adjustments. The machine can bend multiple bars simultaneously, ensures uniform size and accuracy, is portable, and has a sleek design.

The article [V] examines how the bend radius and angle affect stress concentration in aluminum sheets. It aims to assess the influence of these factors based on existing

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research. The results suggest that optimizing the metal-forming process reduces energy and time consumption, improves accuracy, and reduces errors.

The study [VIII] examines a bending process in which a press exerts a high impact force on the die-hold component. Manual bending is more time-consuming and labor-intensive, resulting in longer cycle times, inconsistencies, and unreliability, which lead to inefficiency and decreased customer satisfaction. This paper proposes the development of an automatic bending machine. Once operational, automation is expected to reduce cycle times and costs, enhance product quality, increase productivity, simplify operations, and enable seamless integration with business systems. The new bar-bending machine replaces manual tools and operates semi-automatically, utilizing electric motors, gearboxes, and other components to reduce manual effort and lower costs by decreasing labor requirements.

To address the high steel consumption currently observed, a steel-bending machine with an adjustable rack has been developed [III]. This design involves selecting an appropriate power source and integrating an efficient deceleration system along with an operating system. The deceleration system comprises belts, gears, shafts, and keyways, while the operating system includes a rotating support block, lead screw, lead screw base, bending core, working plate, and additional components. It also evaluates the performance of critical parts of the bending machine. This design enables control of bending speeds up to 20 m/min and supports bending diameters from 18 to 28 mm.

The study [VII] outlined the calculation, design, and manufacturing of a bending machine for bending pipes and V-shaped steel. It aims to develop a device capable of bending standard steel of various sizes, thereby reducing both time and labor. By leveraging principles of plastic deformation, this machine adjusts the bending force for different materials without requiring heating, thereby preserving material integrity.

The [VI] project concentrated on creating an automated machine for bending steel profiles. It uses physical formulas, material strength concepts, and simulation software to precisely calculate the required bending force, thereby aiding the selection of suitable motor and machine configurations. The project also involves designing parts with Autodesk AutoCAD and Autodesk Inventor, applying accurate mechanical manufacturing techniques, assembling the components, and conducting performance testing. Findings indicate that this bending machine can process large steel beams and offers greater capacity at a lower cost than commercial alternatives.

The article [I] explained how a metal-bending machine was designed and built to shape an 8-foot-wide metal plate into various curves, angles, and forms. It uses mild steel plates for the clamp and bending beam. To improve its performance, a 67 kg counterweight is bolted onto the bending beam. The bending plate measures $2.4 \times 0.24 \times 0.015$ meters. Parts are assembled using mechanical clamps and arc welding, then ground, sandblasted, and painted for appearance. The machine can bend metal plates up to 2.4 meters long and 3 mm thick. Testing showed that the angular deformation of the metal plate is inversely proportional to its thickness.

The article [IV] emphasized the importance of designing and developing tube-bending machines suitable for various industrial applications, such as construction and automotive sectors. This project aims to develop an efficient, cost-effective machine

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capable of bending tubes of various sizes and materials. It involves analyzing current bending techniques, selecting suitable materials for components, and implementing a mechanical system to ensure smooth, precise bends. The result will be a functional prototype that can bend pipes of diverse diameters and thicknesses with minimal distortion, lower costs, and maintained performance and accuracy.

The article [II] details a fully servo-controlled four-axis bending machine equipped with a human-machine interface. Designed for high-precision, scalable, and stable production of various curved components, it utilizes a modular, symmetrical roller system and a hierarchical, distributed motion-control architecture. Static system simulations were optimized via SolidWorks, while dynamic bending was modeled with ABAQUS. Experimental results demonstrate that the machine maintains approximately 1% bending error and an average forming error of approximately 0.798%, with a notable decrease in residual straight-edge, indicating broad potential for adoption.

Small and medium mechanical workshops often rely on manual 3-axis hydraulic bending machines to create truck front bull bars. These machines commonly encounter problems like software malfunctions, outdated systems, and a limited selection of market options. Calculating bending coordinates manually is time-consuming and error-prone, especially when performing multiple bends, thereby reducing productivity and posing safety hazards. To address these issues, developing innovative solutions—such as specialized software for these machines and the use of off-the-shelf electrical components—is crucial for reducing costs and improving efficiency.

This article discusses an advanced control system that enables users to input coordinates or extract data from CAD files, ensuring precise cylinder movements and accurate bending. The automation improves efficiency and consistency, greatly reducing the need for human intervention in production.

II. Technical improvement solutions

The system includes:

- o Linear sensors measuring X, Y cylinder stroke
- o Linear valves and 4/3 solenoid valves are replacing the valves of the old system
- o PLC receiving control commands, HMI communication, Ethernet
- o CAD file processing software (DXF) to convert to machine coordinates

Users can:

- o Enter X, Y coordinates directly on the HMI (semi-automatic mode)
- o Send DXF files from the computer, the application will convert the bend path into a list of X, Y coordinates to upload to the PLC (automatic mode)

III. Model converted from CAD file to machine coordinates

Fig. 1 shows the bending diagram of the truck front bull bar.

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With:

H: Distance between roller 1 and roller 3 centers (mm)

a: Distance between roller 2 and roller 3 centers (mm)

b: Steel bar thickness (mm)

R0: Required radius (mm), R1: Roller 1 radius (mm)

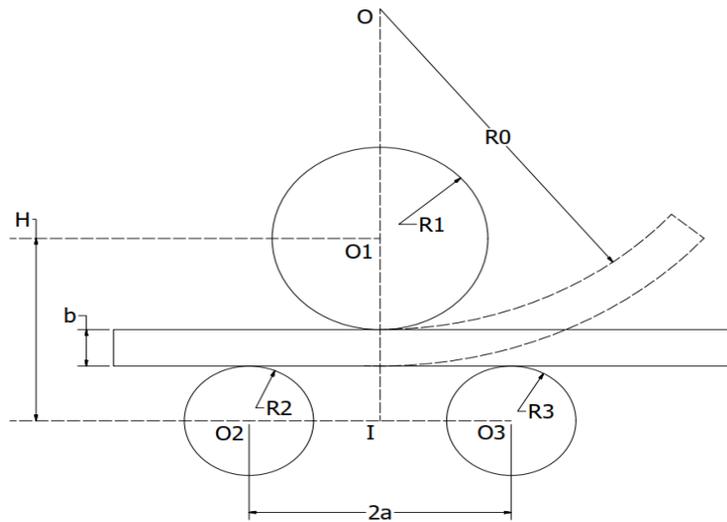R2: Roller 2 radius (mm), R3: Roller 3 radius (mm)

Fig. 1. The bending diagram of the truck front bull bar

Fig. 2 presents the process of converting 3D products into input CAD files using 3D design software

The CAD data processing uses DXF as the input format, representing the pipe profile to be bent as POLYLINE segments. MATLAB is used to read and extract the coordinates of specific points along the profile.
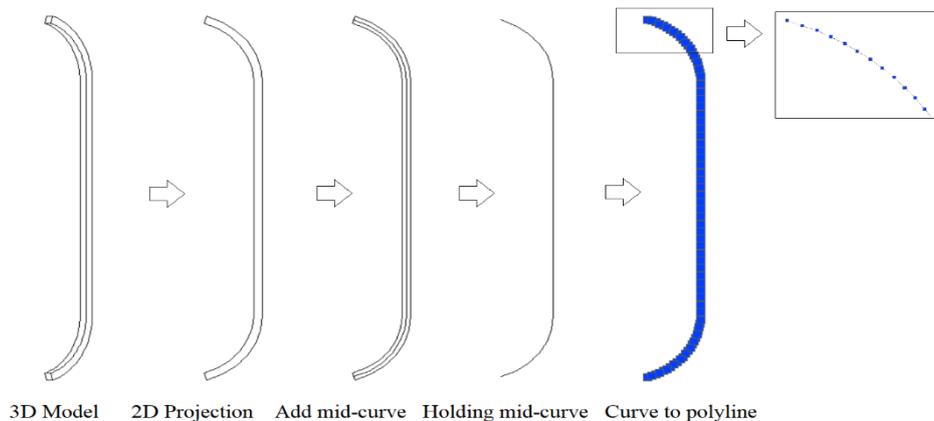

3D Model   2D Projection   Add mid-curve   Holding mid-curve   Curve to polyline

Fig. 2. The conversion of 3D products into input CAD files

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From three consecutive points A, B, and C, the system determines the radius of curvature R using the geometric formula:

$$R = \frac{a \times b \times c}{4 \times S} \text{ (mm)} \tag{1}$$

Where

a, b, and c: lengths of sides of a triangle formed by points A, B, and C (mm)

S: Area of triangle using Heron's formula (mm²)

Calculation of X- and Y-cylinder strokes: Using the machine's three-roller model, the system converts bending path segments into the corresponding hydraulic cylinder strokes.

- o   The X-axis shows the length of the product flattening.
- o   The Y-axis adjusts the displacement of the middle roller, which corresponds to the bending radius.

Output coordinate list: After processing, the system generates a coordinate array in the form $[(X_1, Y1), (X2, Y2), ..., (Xn, Yn)]$ and saves it to the PLC to control bending based on the program.

IV.   Calculate the amount of elastic recovery and build the compensation function:

The truck front bull bar is bent from 40 mm square steel, 3 mm thick, L = 245 mm long, with a cross-section shown in Fig. 3.

Test results of some necessary indicators on the SANS PowerTest equipment at Ho Chi Minh City University of Technology and Education (HCMUTE), Ho Chi Minh City, Vietnam: Young's modulus E = 200 GPa, elastic limit/strength σ = 394.2 MPa.
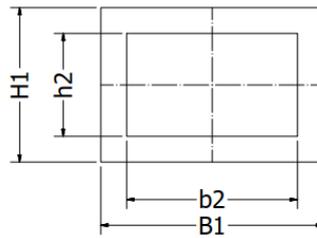
H1 = B1 = 40 mm, h2 = b2 = 34 mm

Fig. 3: A cross-section of square steel for bending

During the bending process, the three-roller system resembles a cantilever beam diagram, as shown in Fig. 4.

Force at free end:

$$F = \frac{\sigma}{L} \times \frac{(H_1^{3}B_1 - h_2^{3}b_2)}{6 \times H_1} \text{ (N)} \tag{2}$$

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Deflection at free end:

$$\delta = \frac{4 \times F \times L^3}{E \times (H_1^3 B_1 - h_2^3 b_2)} \ (mm) \tag{3}$$

Substituting the values listed above into Eqs. (2) and (3):

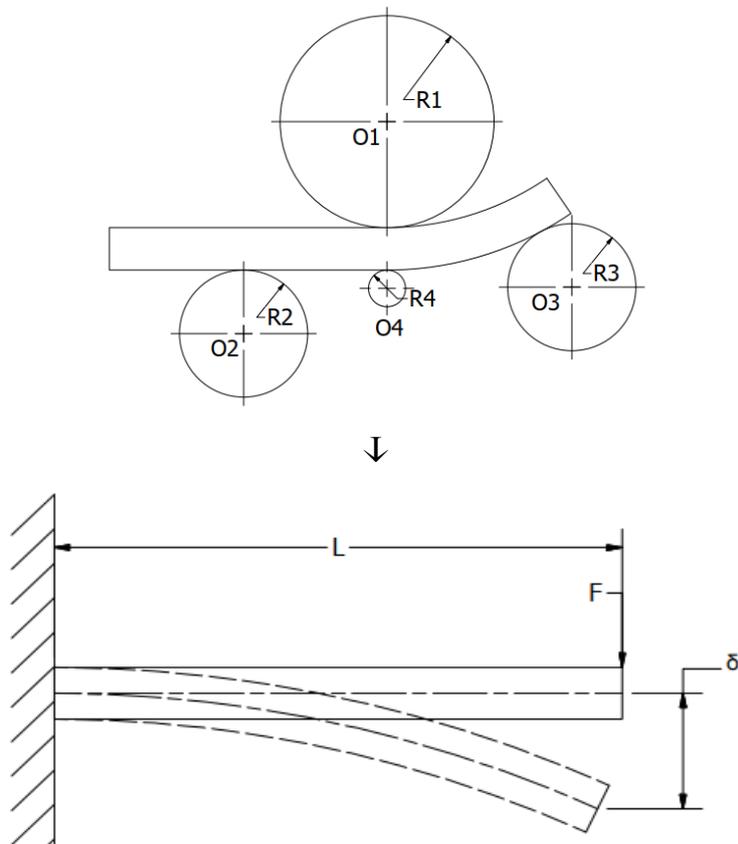- o F = 4792.1 (N)
- o δ = 5.94 (mm)

Fig. 4. A three-roller system is referred to as a cantilever beam diagram

Using the calculated F and δ values, along with the bend profile and dimensions, as well as the machine structure, the compensation function can be developed. At the same time, based on the stress-strain curve from testing the sample on the SANS PowerTest equipment, the corresponding stress is interpolated, and each Y coordinate is derived from CAD to determine the amount of displacement to be compensated.

Original position correction: In the three-roller mechanism, when the steel billet is in uniform contact with the three rollers, the original position of the Y cylinder is not 0, but rather Y0 = 27.0 mm. Therefore, the entire Y series will be compensated by this value.

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V. Results and discussion

The inlet profile of the truck front bull bar is shown in Fig. 5.

Fig. 5. Input profile from CAD file

The system was evaluated in two modes: semi-automatic, in which X and Y coordinates were manually entered, and automatic, in which coordinates were extracted directly from the CAD file. For product code "NOC GL," the CAD data indicates the end curves at Y = 92.3 mm and the middle section at Y = 33.11 mm. In contrast, when using semi-automatic mode with manually entered coordinates, the measured values are Y = 96 mm and Y = 32.82 mm.

Fig. 6 presents a chart comparing calculated and manually entered X-Y coordinate data based on the machine structure.
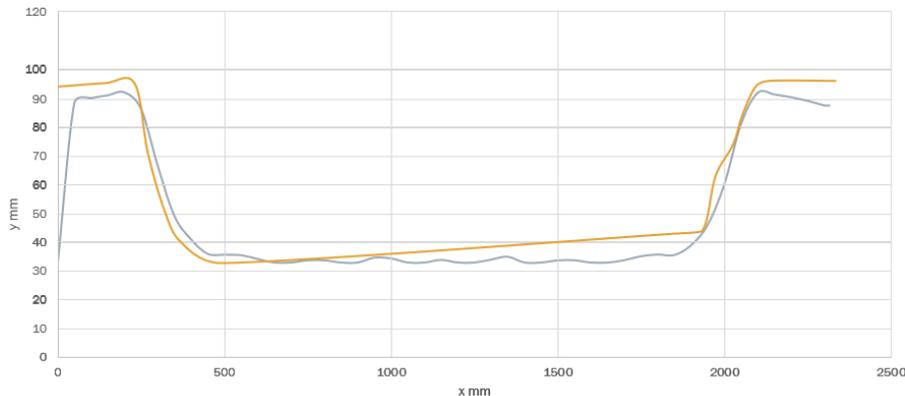

Fig. 6. Calculated data (gray) and manually entered X and Y coordinates (orange)

Fig. 7 compares the product image derived from CAD data with the actual data.
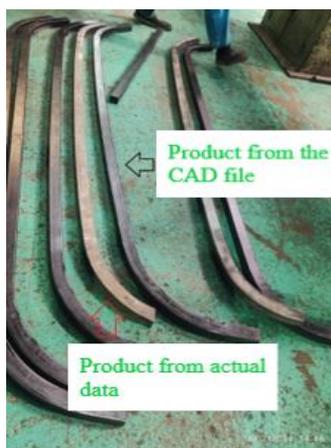

Fig. 7. Product images are calculated from the CAD file and actual data

The image of the successfully bent product is shown in Fig. 8.

Fig. 8. Product image after bending is completed

The results indicate that using the automatic mode, which incorporates the mathematical model and compensation factor, significantly improves accuracy.

- o The error at the end of the curve was decreased from 3.7 mm (entered manually) to approximately 0.3 mm.
- o At the mid-body, the error decreased from approximately 0.3 mm to less than 0.1 mm.

The comparison chart between CAD data (gray) and manually entered data (orange), as shown in Fig. 6, clearly demonstrates the repeatability error occurring during manual operation. Meanwhile, the automatic mode more closely follows the design contour.

Additionally, the bending error is reduced to < ±0.5 mm. Repeat speed is twice that of manual operation. Data from the CAD file provides bending results that match the design. Ensure performance for mass production.

VI. Conclusion

The article significantly enhances the hydraulic pipe-bending machine by upgrading it from manual to semi-automatic and automatic modes through the integration of advanced control technologies, including PLC, HMI, linear sensors, and CAD software. It emphasizes developing a mathematical model to process DXF files, transform them into control coordinates, and calculate compensation coefficients to counteract elastic deformation during bending.

The design of the mathematical model, combined with the interpolated elastic compensation function derived from experimental tension and compression data, has yielded highly favorable results. The automated control system allows for precise bending of complex curves, achieving an error of less than ±0.5 mm relative to the design drawing. Additionally, it improves the uniformity and repeatability across different products.

In summary, this innovative solution enhances both accuracy and productivity while providing opportunities for expansion and integration into modern production lines.

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Looking ahead, future developments may incorporate features such as automatic contour recognition, machine vision, and network connectivity for remote management and monitoring of production.

VII. Acknowledgment

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

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