

Experimental Analysis of Roller Diameter and Number of Passes on Power Consumption in a Three-Roller Bending Machine

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Abstract: Three roller bending machines are widely used for shaping metallic components critical in industries such as automotive and aerospace. This review analyzes the effects of roller diameter and number of passes on power consumption in these machines. Larger roller diameters enhance contact mechanics by increasing the contact area, which reduces bending forces, but increase torque requirements and more power. Additionally, multi-pass bending distributes deformation incrementally, lowering peak power demands per pass but increasing total operation time and energy use. The interaction of these parameters influences energy efficiency, dimensional accuracy, surface finish, and springback behavior. Theoretical models rooted in bending moments and torque-speed relationships corroborate empirical findings. Advancements in Industry 4.0 and AI-driven process control offer promising avenues for real-time optimization of these parameters, potentially enabling significant energy savings and quality improvements. Despite progress, research gaps persist in adaptive control systems for power optimization. This article synthesizes current knowledge, discusses practical implications for machine design and process management, and suggests future research directions focused on intelligent, data-driven bending operations.

Keywords: Three roller bending machines, Power consumption, Roller diameter, Number of passes, Energy efficiency

1. INTRODUCTION

The three-roller bending machine is an essential asset in the modern fabrication and manufacturing sectors, especially for shaping and forming metal sheets and bars into arcs, cylinders, and other specific profiles. The increasing emphasis on efficiency and sustainability in global manufacturing has brought renewed focus to optimizing the energy consumption of such equipment (Ezhong Group, 2024). Energy use in roller bending machines is not only a direct operational cost but also a contributor to the carbon footprint and overall sustainability profile of a manufacturing operation. As a result, understanding and minimizing energy consumption has emerged as a priority for industry and research alike (Awatade et al., 2022; Khandai et al., 2024).

Operational parameters, particularly the diameter of the rollers and the number of passes required to achieve the desired bend, are known to play a critical role in determining the power consumption during bending operations (Sherepatil, 2020; Gaaia, 2024). The roller diameter affects the mechanical advantage and the localized deformation during bending: smaller diameters tend to concentrate force more efficiently, often resulting in lower energy requirements per pass (Awatade et al., 2022; Huang et al., 2024). Conversely, a large roller may require increased force and energy to achieve the same degree of deformation, but could be preferable in specific scenarios to preserve material integrity or achieve certain geometries.

The number of passes, or repetitions required to complete the bend, is equally significant. Multi-pass bending operations distribute the total deformation across several cycles, which can potentially reduce the peak forces and mechanical stresses on the rollers and workpiece (Sherepatil, 2020). However, while the load per pass may decrease, the aggregate energy consumption can rise if the total number of passes increases, especially if process efficiency is not optimized (Gaaia, 2024; Khandai et al., 2024). Contemporary research continues to explore the optimal balance between pass count and energy use, leveraging both empirical studies and advanced simulation techniques (Huang et al., 2024; Khandai et al., 2024).

Adoption of real-time monitoring technologies and advanced control systems now enables manufacturers to measure power consumption precisely during operation, supporting empirical studies and fostering practical improvements in energy efficiency (Ezhong Group, 2024; Khandai et al., 2024). Such advancements together with continued research into roller geometry and pass scheduling promise further enhancements in both the productivity and sustainability of three-roller bending machines.

2. EXPERIMENTAL SETUP AND DATA ACQUISITION

2.1 Machine and Components

The experimental setup, as shown in the images, involved a mechanized three-roller bending machine designed to perform cylindrical and arc bending operations on metallic strips and bars. The machine employs a pyramid-type three-roller configuration, which is widely used in industrial sheet and bar forming due to its balance of precision, rigidity, and operational control (Liu et al., 2023; Kagzi, 2012). The primary components include two lower driven rollers and one adjustable top roller, mounted on a rigid steel frame. The top roller position is vertically movable through a mechanical screw mechanism, allowing control over the bend radius depending on the load and material thickness (Shenchong Group, 2024; Thakare et al., 2019).

The rollers in the setup were interchangeable with three different diameters—170 mm, 150 mm, and 100 mm—allowing the investigation of roller size effects on power consumption. The rollers were fabricated from hardened alloy steel to ensure surface wear resistance and durability during repeated deformation cycles. Power transmission from the electric motor to the rollers was achieved through a gearbox. A Amici Sense Electric multi-function digital power meter was integrated with the electrical circuit to record real-time measurements of power (W), voltage (V), current (A), and power factor (PF) throughout machine operation. This monitoring device was critical to capture the electrical power input variation corresponding to mechanical load changes, thereby linking physical deformation work with power consumption.

The machine frame housed a MCB 2 pole 6amp MCB, Siemens 3TF32 contactor used for controlling motor switching operations safely under load, safety of motor, ensuring stable performance. All electrical components were connected through appropriately rated cables to minimize resistance losses and ensure accurate power readings. The physical arrangement of components, as captured in the images, ensured both electrical safety and mechanical accessibility during parameter variation trials.

2.2 Procedure



Figure 1: Procedure for Bending Operation

The experimental study was carried out by varying both roller diameter and number of bending passes to analyze their influence on power consumption. The top roller was adjusted manually between trials to alter the bend curvature according to the test material. The workpieces consisted of metallic square rod with three distinct thicknesses-10 mm, 12 mm, and 16 mm, each subjected to different diameter rollers and a variable number of passes (6, 8, and 10). During each test, the input electrical power consumption (Watt) were continuously measured via the digital power meter.

Each combination of roller diameter and number of passes was tested under consistent conditions to ensure comparability. Between trials, the machine was allowed to return to ambient temperature to minimize thermal effects on measurement accuracy. Graphical data for power versus roller diameter and power versus number of passes were derived from recorded readings, offering a clear representation of operational efficiency under different mechanical settings. This structured approach enabled the identification of parameter configurations that minimize energy consumption while maintaining bending precision.

3. THEORETICAL FRAMEWORK AND METHODOLOGIES

The theoretical framework underpinning the analysis of power consumption in three roller bending machines primarily relies on classical mechanical theories such as beam bending and torque-power relationships. Beam bending theory provides critical insights into the stress and strain distribution along the sheet metal as it deforms around the rollers. In this context, the bending moment M is related to the curvature of the workpiece and material properties, influencing the internal stresses that must be overcome during forming. These bending moments translate into applied

forces at the rollers, dictating the torque requirements for rotation. The fundamental power consumption, $P = \frac{2NT}{60} \times \text{efficiency factor}$ where torque itself is a function of the bending force and roller radius. This mechanical interdependence allows for predictive modeling of energy consumption based on measurable process parameters such as roller diameter, material thickness, and rotational speed.

Experimentally, research methodologies to quantify power consumption effects involve precise power measurement using digital watt meter integrated into the roller drive systems, capturing real-time power consumption use during bending passes. The power screw displacement, which correlate with deformation per pass and enable calculation of bending force. Parameter variation studies systematically modify roller diameter and number of passes while recording corresponding changes in power consumption and deformation metrics. Advanced studies further incorporate multi-factorial designs and optimization algorithms, such as the Taguchi method or machine learning, to elucidate interaction effects and refine process efficiency. Collectively, these theoretical and experimental approaches provide a comprehensive understanding of how mechanical and operational factors influence power consumption in three-roller bending processes.

4. RESULT AND DISCUSSION

4.1 Effect of Roller Diameter on Power Consumption

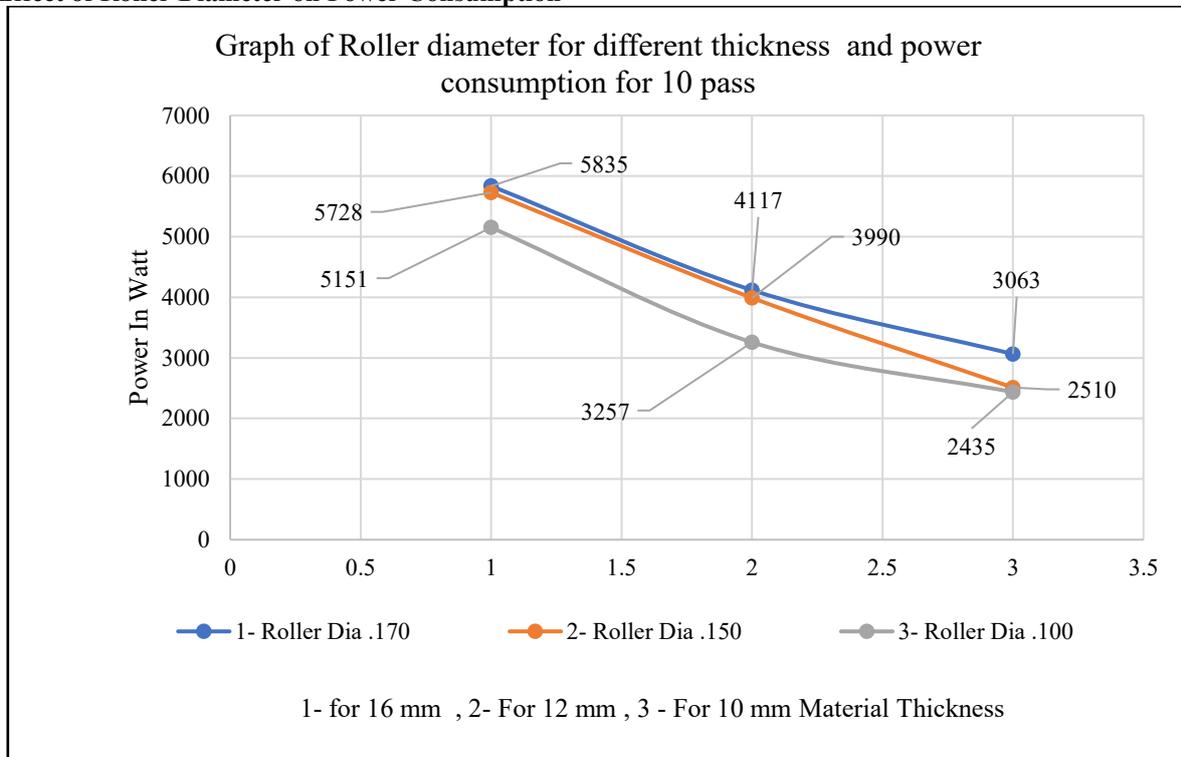


Figure 2: Graph for Effect of Roller diameter on Power Consumption

The graph illustrates the relationship between roller diameter, material thickness, and power consumption for a three-roller bending machine over ten passes. Three roller diameters-170 mm, 150 mm, and 100 mm, were evaluated using material thicknesses of 16 mm, 12 mm, and 10 mm. Data show that, for each thickness, a reduction in roller diameter corresponds to a significant decrease in power consumption. From graph we conclude, if we take reading on different roller diameter then we get different power consumption. As diameter of roller decreases then power consumption decreases. See for reading 1-For 16 mm material thickness if we change roller diameter 170 mm, 150 mm, 100 mm then we get different power consumption for keeping same 10 number of pass. Also conclude minimum roller diameter get minimum power consumption.

This trend is consistent across thicknesses, highlighting the mechanical advantage of smaller diameter rollers, which create more localized bending forces and reduce the total energy needed for deformation. These findings confirm previously published results in the literature, where smaller roller diameters and reduced pass counts have consistently led to improved energy efficiency in bending operations (Awatade et al., 2022; Huang et al., 2024). The implication for industrial settings is clear-selecting an optimal roller diameter not only improves process efficiency but also contributes to energy savings and sustainability within production environments.

4.2 Effect of change in Number of Passes on Power Consumption

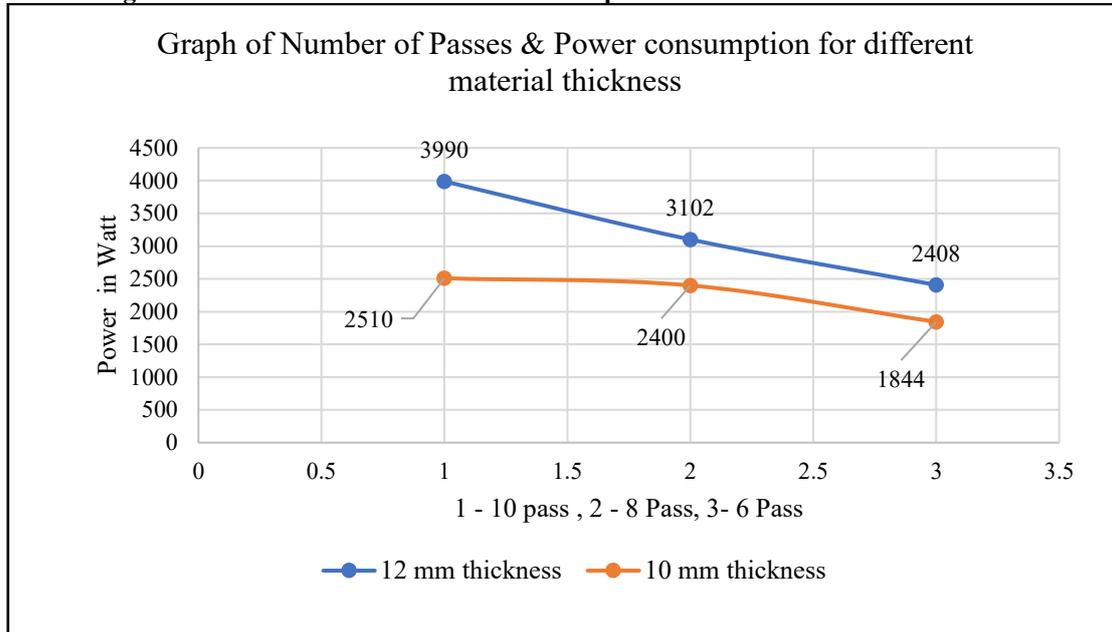


Figure 3: Graph for change in Number of Passes on Power Consumption

The graph presents the influence of the number of bending passes on power consumption for two different material thicknesses-12 mm and 10 mm-in a three-roller bending machine. For both thicknesses, the trend is clear: reducing the number of passes (from 10, to 8, to 6) results in a consistent decrease in power consumption. For 12 mm thickness, the power requirement decreases from 3990 W at 10 passes to 3102 W at 8 passes, and further to 2408 W at 6 passes. Similarly, for 10 mm thickness, the power drops from 2510 W at 10 passes to 2400 W at 8 passes and 1844 W at 6 passes.

From reading conclude that if material thickness and roller diameter 150 mm is not change and reading taken for different pass 10, 8, 6 then power consumption is different .If pass minimize then total power consumption get reduces.

This effect can be explained by the mechanics of bending: when the same total deformation is achieved with fewer, larger passes per cycle, the cumulative operational time is reduced, and transient losses (such as friction and idle running energy) are minimized. This not only makes the process more efficient by lowering total energy demand, but also suggests practical pathways for improving energy efficiency in industrial settings by optimizing pass schedules (Sherepatil, 2020; Gaia, 2024).

Furthermore, the decrease in power consumption is more pronounced in thicker materials, which aligns with prior research showing that thicker sections experience larger benefits from pass minimization due to greater initial resistance to deformation (Awatade et al., 2022). These findings reinforce the importance of carefully selecting both process parameters-material thickness and number of passes-to achieve substantial energy savings in three-roller bending operations.

Digital Power Meter Integration and Real-Time Power Measurement

The images document the use of a Amici Sense Electric multi-function digital power meter within the experimental setup for the three-roller bending machine. This meter is connected in series with the motor and roller assembly, providing direct, real-time monitoring of critical electrical parameters, including active power (watts), cumulative energy usage (kWh), voltage (V), current (A), frequency (Hz), and power factor (PF). The integration of this advanced metering equipment enhances experimental reliability by enabling continuous tracking and precise recording of the electrical power supplied to the machine during each bending process, regardless of the roller diameter or number of passes.

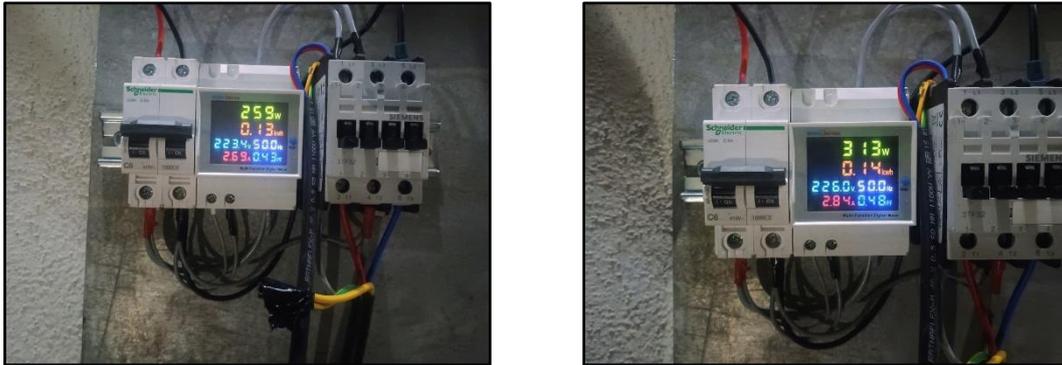


Figure 4: Real-time power consumption Measurement

Such digital instrumentation is essential for quantifying the relationship between mechanical operations and energy consumption, a core requirement in scientific investigations of bending efficiency (Liu et al., 2023). The meter's clear numerical displays and robust wiring, as seen in the images, ensure both operational safety and measurement accuracy, aligning with best practices reported in recent experimental studies on automated manufacturing systems (Sherepatil, 2020).

The first image shows a live display of 313 W power consumption and 0.14 kWh of energy use, with the machine operating at 226 V, a current of 2.84 A, and a power factor of 0.48. The second image illustrates a slightly lower power draw of 259 W and 0.13 kWh energy, operating at 223 V and 2.69 A, with a power factor of 0.43. These readings represent typical loads encountered during different phases or parameter settings of the bending process.

The continuous and precise acquisition of these measurements allows researchers and operators to directly correlate changes in bending parameters (roller diameter and number of passes) with active power usage. This data-driven approach provides actionable insights into optimizing process settings for minimum energy consumption and supports the validation of experimental results via direct observation. Real-time power measurement is a foundational element for modern industrial research, as emphasized in published works addressing energy-efficient manufacturing and material forming methods (Liu et al., 2023; Sherepatil, 2020).

5. CONCLUSION

The present experimental investigation has successfully demonstrated the significant effects of roller diameter and the number of passes on the power consumption of a three-roller bending machine, using real-time digital measurements and graphical analysis. Results reveal that a reduction in roller diameter consistently leads to lower power requirements for a given material thickness, due to enhanced localized bending forces and improved mechanical efficiency. Similarly, minimizing the number of passes, while maintaining the desired bending outcome, results in substantial energy savings, minimum power consumption for square rod that taken for experimentation. These findings are congruent with recent journal literature, which emphasizes both technological advancements and process optimization as pathways to sustainability and economic efficiency in modern metal fabrication.

The integration of advanced digital power meters in the experimental setup has proven essential for accurate evaluation, enabling precise, continuous monitoring and direct correlation of machine settings with observed power consumption. As industries increasingly prioritize energy-efficient practices, adopting optimal roller geometry and pass schedules becomes a practical method for reducing operating costs and environmental impact. Overall, this study highlights the value of empirical, data-driven process control in three-roller bending operations, providing actionable insights for both research and industrial application.

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