JoFRISE 4 (1) (2026)
Journal of Frontier Research in Science and Engineering
https://journal.riau-edutech.com/index.php/jofrise
Publisher :
Andester Riau Edutech
Pusat Inovasi Pendidikan dan Teknologi
ISSN : 3032-0348

Design and Development of a Metal Forging Prototype Using a Wheel-Axle System and Electric Motor Drive

Sylvia Anjani[1]*, Teti Novrianti[1], Riza Andriani[1]

[1] *Physics Education, Faculty of Teacher Training and Education, Riau University, Indonesia*

*Corresponding author's email: sylvia.anjani3593@student.unri.ac.id

Submiited: 28/02/2026
Review: 24/03/2026
Accepted: 26/03/2026
Published: 30/03/2026
Vol. 4
No. 1

Abstract- The increasing demand for metal products in industrial and agricultural sectors necessitates the development of efficient and accessible forging technologies, particularly for small-scale blacksmith industries. Traditional forging methods rely heavily on manual labor, resulting in low productivity, inconsistent output, and high physical strain on operators. This study aims to design and evaluate a prototype metal forging tool utilizing a wheel–axle mechanism integrated with an electric motor to enhance operational efficiency. The research adopts a Research and Development (R&D) approach using the ADDIE framework, encompassing design, fabrication, and experimental testing of the prototype. Performance evaluation was conducted by comparing the number of hammer strikes generated manually and by the prototype within identical time intervals. The results reveal a substantial improvement, with the prototype producing an average of 64.25 strikes per 10 seconds compared to 25.25 strikes using manual methods, corresponding to an efficiency increase of 154.46%. These findings demonstrate that the proposed system effectively improves productivity, reduces operator fatigue, and provides a cost-effective and practical solution for modernizing small- and medium-scale forging industries.

Keywords: *electric motor, forging, mechanical system, productivity, wheel and axle.*

1 Introduction

The rapid advancement of industrial development has significantly increased the demand for metal-based products across various sectors, including construction, transportation, agriculture, and household industries. This growth is closely associated with infrastructure expansion, technological innovation, and the continuous need for durable and reliable tools. In many developing regions, particularly rural areas, metal tools such as machetes, hoes, knives, and chisels remain essential for daily activities and agricultural productivity. These tools are predominantly produced through traditional blacksmithing processes, which rely on simple equipment and manual labor. Despite their cultural and economic importance, traditional forging practices face increasing pressure from mass-produced industrial goods that offer lower costs and standardized quality (Siahaan et al., 2023; Sutrisno et al., 2020). As a result, small-scale blacksmith industries are struggling to maintain competitiveness in modern markets. This situation highlights the urgent need for technological interventions that can improve productivity while preserving the accessibility and sustainability of traditional metalworking practices.

One of the primary challenges in traditional forging processes is the heavy dependence on human labor, particularly in the repetitive hammering stage used to shape heated metal. This manual approach not only limits production capacity but also leads to significant physical fatigue and inconsistencies in output quality. Previous studies have shown that manual forging can produce only a limited number of strikes per minute, restricting overall efficiency and productivity (Septiawan et al., 2023). Several technological

How to Cite
Anjani, S., Novrianri, T., & Andriani, R. (2026). Design and Development of a Metal Forging Prototype Using a Wheel-Axle System and Electric Motor Drive. Journal of Frontier Research in Science and Engineering (JoFRISE). 4 (1), 31-37

solutions have been proposed, such as lever-based forging machines and motor-driven hammer systems, which demonstrate improvements in productivity. However, these systems often suffer from limitations such as mechanical instability, high energy consumption, or complex operational requirements (Ramadhan & Fitriani, 2022). Advanced automated systems using programmable controllers offer higher precision but are generally expensive and difficult to maintain, making them unsuitable for small-scale industries. Therefore, there remains a significant research gap in developing a forging system that is efficient, stable, affordable, and easy to operate, particularly for small and medium enterprises (Fauza, 2025).

The forging process is fundamentally governed by several core principles of physics, including Newton's Second Law, work and energy, rotational dynamics, and energy conversion. Newton's Second Law describes how the force applied to a hammer is related to its mass and acceleration, directly influencing the impact force delivered to the metal (Gundlach et al., 2007). Additionally, the concept of work and energy explains how mechanical work is performed when force causes displacement, while kinetic energy determines the effectiveness of hammer strikes during the forging process (Niyanti et al., 2022). Rotational dynamics plays a crucial role in mechanical forging systems, where torque generated by rotating components drives the hammer mechanism. The wheel–axle system, in particular, provides mechanical advantage by amplifying force while controlling motion. Furthermore, the process of converting electrical energy into mechanical energy through an electric motor enables continuous and consistent operation. These theoretical principles provide the scientific foundation for designing a more efficient and reliable forging system.

To address the identified challenges, this study proposes the development of a prototype metal forging tool that integrates a wheel–axle mechanism with an electric motor drive system. Unlike previous designs that focus on either manual assistance or complex automation, this prototype emphasizes simplicity, efficiency, and cost-effectiveness. The use of a pulley and belt transmission system allows for smooth and continuous transfer of rotational motion from the motor to the hammer mechanism, ensuring stable and repetitive striking motion (Dier, 2025). The novelty of this research lies in the optimization of mechanical and electrical components into a compact system that can be easily assembled and operated without requiring advanced technical expertise. By focusing on accessibility and practicality, the proposed design aims to bridge the gap between traditional forging methods and modern industrial technologies. This approach aligns with the concept of appropriate technology, which prioritizes solutions that are adaptable, affordable, and relevant to local needs.

Based on the background and research gap identified, the main objective of this study is to design, develop, and evaluate a prototype metal forging tool that improves productivity and operational efficiency compared to manual methods. The study specifically focuses on analyzing the performance of the prototype in terms of hammer strike frequency within a fixed time interval as an indicator of efficiency. In addition to quantitative performance evaluation, the research also considers practical aspects such as system stability, ease of operation, and potential application in small-scale industries (Pratiwi et al., 2025). The expected contribution of this study is to provide an innovative yet practical solution that enhances the competitiveness of traditional blacksmith industries while reducing physical workload. Furthermore, the findings are expected to contribute to the broader field of applied physics and mechanical engineering by demonstrating how fundamental physical principles can be effectively integrated into real-world technological solutions.

2 Research Methodology

This study employed a Research and Development (R&D) approach aimed at designing, constructing, and evaluating a prototype metal forging tool based on a wheel–axle system and an electric motor drive. The development process followed the ADDIE framework (Analysis, Design, Development, Implementation, and Evaluation) to ensure a systematic workflow. In the analysis stage, key problems in traditional forging were identified, particularly low productivity and high physical workload. The design stage involved conceptualizing the mechanical system, including the integration of the motor, pulley, and hammer mechanism. During the development stage, all components were assembled into a functional prototype. The implementation stage was limited to laboratory-scale testing due to constraints in time and resources. Finally, evaluation was conducted by comparing the performance of the prototype with manual forging methods. This structured approach ensures that the resulting system is both technically functional and practically applicable for small-scale industrial use.

2.1 Experimental Setup and Prototype Construction

The prototype was constructed using a combination of electrical and mechanical components, including a DC motor (dinamo), pulley system, belt transmission, shaft, hammer arm, and power supply (battery). The supporting structure was built using plywood and acrylic materials to ensure stability while maintaining simplicity and affordability. The electric motor functioned as the main energy source, converting electrical energy into rotational motion. This rotation was transmitted through a belt and pulley system to drive a swinging arm connected to the hammer. The hammer mechanism was designed to move periodically, producing repetitive impacts similar to manual forging. Proper alignment of all components was carefully ensured to minimize friction and energy loss, thereby improving efficiency. The system was tested under controlled conditions to verify its operational stability, consistency, and functionality. The prototype represents a simplified semi-automatic forging tool that is suitable for small-scale applications.

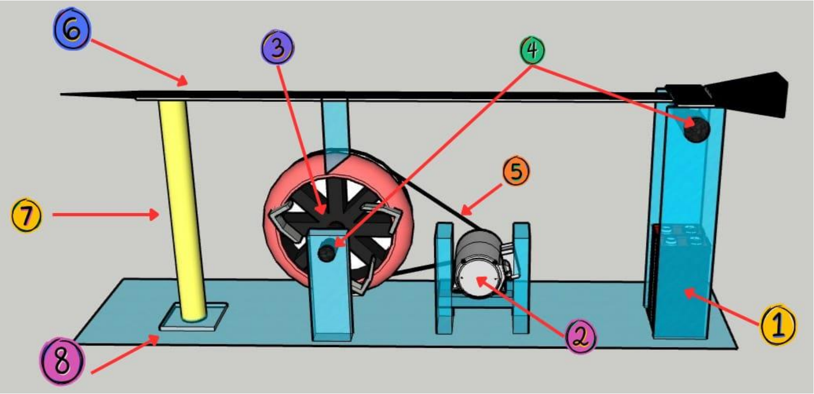

Figure 1. Tool Design

Code Number:

1. Battery: As a source of electrical energy supplied to the dynamo
2. Dynamo: As a converter of electrical energy into mechanical energy
3. Pulley Wheel: As a component that transmits power from the dynamo to the hammer system
4. Shaft: Functions to support the structure of the tool
5. Belt: As a transmission of rotation from the dynamo to the pulley wheel
6. Swing Arm: A long beam connected to the pulley wheel that acts as the driving arm for the hammer
7. Hammer: As the main component that provides impact force to the metal
8. Forging Anvil: As a stable and hard surface where the metal is forged

2.2 Data Collection Techniques

The research utilized quantitative data collection methods, focusing on measuring the number of hammer strikes produced within a fixed time interval. Data were collected through direct observation and measurement using a stopwatch to record the number of strikes within 10-second intervals. Two conditions were tested: manual forging and prototype-assisted forging. Each experiment was repeated multiple times to ensure consistency and reliability of the results. The recorded data were then tabulated and averaged to determine the performance of each method. The number of hammer strikes was selected as the primary variable because it directly represents productivity and operational efficiency in the forging process. By maintaining consistent experimental conditions, such as equal time duration and standardized measurement procedures, the comparison between manual and prototype methods was conducted in a fair and controlled manner.

2.3 Data Analysis Methods

The collected data were analyzed using descriptive quantitative analysis, which aims to interpret numerical data in a systematic and objective manner. The average number of strikes for both manual and prototype methods was calculated and compared to determine the level of performance improvement. Efficiency was evaluated by calculating the percentage increase in strike frequency between the two methods. This approach provides a clear indication of how much the prototype enhances productivity. In addition to numerical analysis, qualitative observations were also considered, including system stability, consistency of hammer motion, and ease of operation. These observations provide additional insights into the practical usability of the prototype. The results of this analysis were used to assess whether the developed tool meets its design objectives and to identify potential areas for improvement in future development.

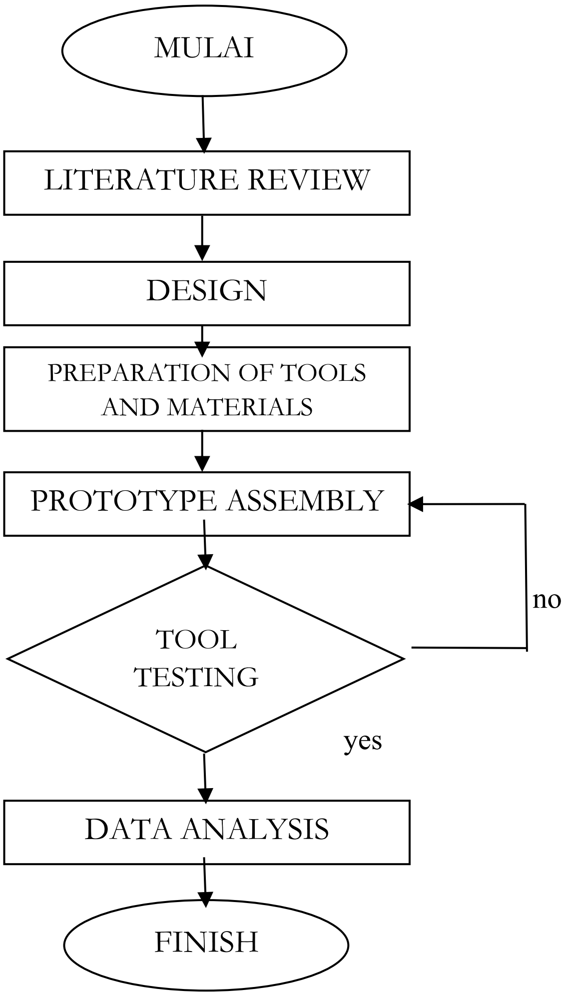

Figure 2. Research Flow

The flowchart illustrates the systematic process of developing and evaluating a prototype metal forging tool. The process begins with a literature review to establish theoretical foundations and identify relevant previous studies. This is followed by the design phase, where the conceptual structure and working mechanism of the tool are planned. Next, the preparation stage involves gathering all necessary tools and materials required for construction. The prototype is then assembled and tested to evaluate its functionality and performance. If the testing results are not satisfactory, the process returns to the assembly stage for improvement. However, if the prototype meets the expected criteria, the process continues to data analysis, where the performance results are examined and interpreted. Finally, the process concludes with the completion stage, indicating that the prototype has been successfully developed and evaluated.

3 Results and Discussion

Experimental Results

The following is the result of the design of a prototype metal forging tool with a wheel-axle system and an electric motor as the drive.

Figure 3. Metal Forging Tool Prototype

Data collection was conducted by testing the functionality of the prototype, namely by observing whether the hammer on the metal forging tool could move up and down normally. Furthermore, the tool's striking frequency was measured over a certain period of time using a stopwatch to determine the tool's consistency and performance. After testing, the research data are presented in Table 1.

Table 1. Comparison Data of Manual and Prototype Hammer Strikes within a 10-Second Interval

No	Time Interval (Seconds)	Number of Strikes (Manual)	Number of Strikes (Using Prototype)
1	10	24	68
2	10	22	63
3	10	26	59
4	10	29	67
	Average	**25.25**	**64.25**

The experimental results indicate a clear performance difference between manual forging and the prototype-assisted method. Data were collected from four repeated trials within a fixed time interval of 10 seconds. The manual forging process produced an average of 25.25 hammer strikes, while the prototype generated an average of 64.25 strikes within the same duration. This substantial increase demonstrates that the prototype is capable of delivering more than twice the output of manual operation. The results also show that the prototype maintains consistent performance across trials, whereas manual forging results fluctuate due to operator fatigue and variations in human effort. The higher strike frequency achieved by the prototype reflects improved productivity and efficiency in the forging process. These findings confirm that integrating a mechanical system driven by an electric motor significantly enhances operational capability, making it suitable for applications requiring repetitive and consistent forging actions.

Discussion of Efficiency and System Performance

The efficiency analysis shows an improvement of 154.46% in strike frequency when using the prototype compared to manual forging. This increase can be explained by the continuous and uniform motion generated by the electric motor, which eliminates human limitations such as fatigue and inconsistency. From a physics perspective, the system efficiently converts electrical energy into mechanical energy through the motor, which drives rotational motion in the pulley system. This rotational motion is then transformed into periodic linear motion of the hammer, enabling repeated impacts with minimal interruption. The use of a wheel–axle mechanism provides mechanical advantage, allowing the system to amplify force while maintaining stability. As a result, the prototype achieves both higher speed and consistent output. These findings are consistent with previous studies that highlight the effectiveness of motor-driven forging systems in improving productivity (Ramadhan & Fitriani, 2022).

Discussion of Practical Implications and Limitations

In addition to performance improvement, the prototype also offers significant advantages in terms of ergonomics and operational efficiency. By reducing the need for continuous manual hammering, the system decreases physical workload and minimizes fatigue, allowing operators to work for longer durations with better consistency. The uniform motion of the hammer also contributes to more consistent shaping of metal, which is important for product quality. However, the prototype still has several limitations. The system produces noticeable vibration and noise during operation, which may affect user comfort. Additionally, the power output is still limited, making it less suitable for forging larger or harder materials. The dependence on electrical energy may also pose challenges in areas with limited power supply. Despite these limitations, the prototype represents a practical and affordable solution that bridges the gap between traditional and modern forging technologies.

4 Conclusion

The results of this study demonstrate that the developed prototype metal forging tool significantly improves the efficiency and productivity of the forging process compared to traditional manual methods. The integration of a wheel–axle mechanism with an electric motor enables continuous and stable hammer motion, resulting in a substantial increase in strike frequency. Experimental findings show that the prototype achieves an average of 64.25 strikes per 10 seconds, compared to 25.25 strikes produced manually, corresponding to an efficiency improvement of 154.46%.

From a scientific perspective, the system successfully applies fundamental physics principles, including energy conversion, rotational dynamics, and mechanical advantage, to enhance operational performance. The prototype also reduces operator fatigue and improves consistency, making it highly suitable for small- and medium-scale industries.

However, the system still has limitations, such as restricted power capacity, vibration, and dependence on electrical energy. Future improvements should focus on increasing motor capacity, enhancing structural durability, and reducing noise and vibration. Overall, this study provides a practical and innovative solution that supports the modernization of traditional forging processes while maintaining accessibility and cost-effectiveness.

Reference

Afdillah, J. (2024). Etnografi Kehidupan Pengrajin Pandai Besi di Jorong Tangah Koto Nagari Sungai Pua. Jurnal Nomosleca, 10(1), 97–127. https://doi.org/10.26905/nomosleca.v10i1.12459

Dier, M. (2025). Analysis of Electric Field Distribution Patterns of Dipoles in Various Vacuum Mediums and Dielectric Materials. 3, 14–19

Fatullah, Y. (2022). Rancang Bangun Alat Mesin Tempa Pandai Besi Sistem Hammer Kapasitas 14 K. 2(2).

Fauza, N. (2025). The Influence of Dielectric Space on Materials Capacitance of Capacitor. 3, 33–38

Firbank, T. C. (1970). Mechanics of the belt drive. International Journal of Mechanical Sciences, 12(12), 1053–1063. https://doi.org/10.1016/0020-7403(70)90032-9

Goren, Y. (2008). The location of specialized copper production by the lost wax technique in the Chalcolithic southern Levant. Geoarchaeology, 23(3), 374–397. https://doi.org/10.1002/gea.20221

Guiggiani, M. (2018). Mechanics of the Wheel with Tire. In M. Guiggiani, The Science of Vehicle Dynamics (pp. 7–65). Springer International Publishing. https://doi.org/10.1007/978-3-319-73220-6_2

Gundlach, J. H., Schlamminger, S., Spitzer, C. D., Choi, K.-Y., Woodahl, B. A., Coy, J. J., & Fischbach, E. (2007). Laboratory Test of Newton's Second Law for Small Accelerations. Physical Review Letters, 98(15), 150801. https://doi.org/10.1103/PhysRevLett.98.150801

Herry Setyawan. (2020). Modul Fisika Kelas XI, KD 3.1. Direktorat SMA, Direktorat Jenderal PAUD, DIKDAS dan DIKMEN.

Hessel, R., Canola, S. R., & Vollet, D. R. (2013). An experimental verification of Newton's second law. Revista Brasileira de Ensino de Física, 35(2), 1–5. https://doi.org/10.1590/S1806-11172013000200024

Irasari, P., Widiyanto, P., Muqorobin, A., & Hikmawan, M. F. (2023). Feasibility analysis of the conversion of brushed to brushless direct current motor. International Journal of Electrical and Computer Engineering (IJECE), 13(1), 218. https://doi.org/10.11591/ijece.v13i1.pp218-228

Meidayanti, I. (2023). Memahami Jenis- Jenis Dari Pesawat Sederhana Serta Analisis Manfaatnya Bagi Banyak Orang. 1(2).

Niyanti, P. E., Setyaningrum, F. P., Rachman, G. W., & Wandita, F. (2022). Implementasi Pembelajaran Fisika Topik Usaha dan Energi Berdasarkan Publikasi Ilmiah. Mitra Pilar: Jurnal Pendidikan, Inovasi, Dan Terapan Teknologi, 1(2), 99–118. https://doi.org/10.58797/pilar.0102.05

Nur Rohmat, Y., Rachmatullah, Maulana Akbar, R., Badruzzaman, Van Gunawan, L., & Ardhian Nugroho, O. (2022). Perancangan Mesin Penggulung Dinamo Semi-Otomatis. Journal of Applied Mechanical Technology, 1(1), 36–45. https://doi.org/10.31884/jamet.v1i1.13

Pratiwi, W., Wahyu, N., Yani, I., Dwi, R., Putri, A., & Desri, D. E. (2025). Transformation Of Electronic Communication Systems Into Optical Communication Systems. 3, 1–6

Rumiati, R., Handayani, R. D., & Mahardika, I. K. (2021). Analisis Konsep Fisika Energi Mekanik Pada Permainan Tradisional Egrang Sebagai Bahan Pembelajaran Fisika. Jurnal Pendidikan Fisika, 9(2), 131. https://doi.org/10.24127/jpf.v9i2.3570

Safitri, R. D., Rayhani, F., & Widya, H. (2024). Konversi Energi Magnetik Ke Energi Mekanik Pada Alat Peraga Menggunakan Kawat Besi. 06.

Septiawan, A., Mukhnizar, M., & Zulkarnain, Z. (2023). Pembuatan Mesin Tempa Logam Dengan System Forging Hammer. Jurnal Teknik, Komputer, Agroteknologi Dan Sains, 2(1), 1–8. https://doi.org/10.56248/marostek.v2i1.41

Siahaan, M. Y. R., Siregar, R. A., Tanjung, F. A., & Saktiawan, A. (2023). Analisis Karakteristik Bahan Tembaga Akibat Pengaruh Proses Penempaan Terhadap Kekuatan Impak. Jurnal Rekayasa Material, Manufaktur dan Energi, 6(1). https://doi.org/10.30596/rmme.v6i1.13709

Sofian, H. O. (2021). Development of Technology Ferrous Metal Melting Furnace Ancient Times in Indonesia. KALPATARU, 30(2), 141–152. https://doi.org/10.24832/kpt.v30i2.863

Sutrisno, O. D., Amirudin, A., Rokhman, T., & -, A. (2020). Rancang Bangun Dan Unjuk Kerja Tungku Tempa Portabel Berbahan Bakar Lpg. Jurnal Ilmiah Teknik Mesin, 8(1), 25–31. https://doi.org/10.33558/jitm.v8i1.2000

Wangchuk, S., & Madan, A. (2021). Recent Advances in Various Types of Forging—A Research Review. International Journal of Science and Research (IJSR), 10(11), 980–982. https://doi.org/10.21275/SR211116185549