

“CNC SPM DEVELOPMENT FOR AUTOMATED SPOT WELDING BETWEEN LI-ION BATTERY AND SHEET METAL CONNECTOR”

Mr. Durgesh Shukla¹, Mr. Bangre Nitinkumar Bhashkar², Mr. Prathamesh M. Kharsade³, Prof. S. R. Gayakwad⁴

¹Mechanical Department & Sharadchandra Pawar college of Engg, Otur

²Mechanical Department & Sharadchandra Pawar college of Engg, Otur

³Mechanical Department & Sharadchandra Pawar college of Engg, Otur

⁴Mechanical Department & Sharadchandra Pawar college of Engg, Otur

Abstract - The escalating demand for electric vehicles (EVs) and portable electronics has intensified the need for reliable, high-capacity lithium-ion (Li-ion) battery packs. This project focuses on the development of an automated spot-welding system designed to connect 18650 Li-ion cells using sheet metal connectors. Manual welding often suffers from inconsistent joint quality, low productivity, and potential thermal damage to cells. To address these challenges, a three-degree-of-freedom (3-DOF) welding machine was designed and implemented using an Arduino-based microcontroller for precise robotic motion control. The research involved a comprehensive parameter study to optimize the resistance spot welding process. Influencing factors—including electrode tip geometry, welding force, supply voltage, welding time, and the distance between electrodes—were investigated through both 3D Finite Element (FE) simulations and experimental validation. Simulation models analysed critical behaviours such as electric current distribution, temperature gradients, and material deformation to ensure joints remained thermally safe and mechanically robust. Experimental results demonstrated that the automated system provides superior consistency in weld strength and nugget size compared to manual methods. Implementation data indicates that the automated approach can significantly increase production output—rising from 300 to 350 units per month—while reducing variable labour costs and consumable waste. Ultimately, this project establishes a scalable, Industry 4.0-ready solution that enhances the safety, durability, and manufacturing efficiency of Li-ion battery assembly.

Key Words: Spot welding, Automation, Lithium-ion batteries, Sheet metal connectors, Parameter optimization.

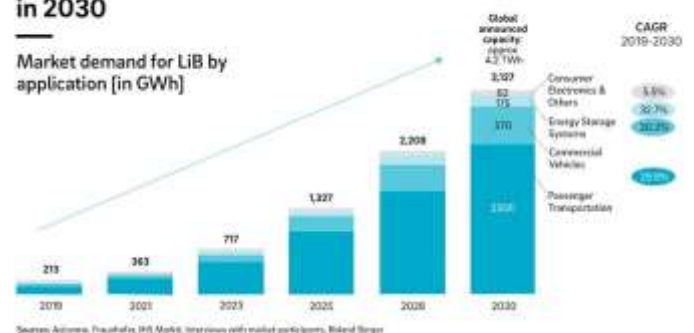
1. INTRODUCTION (Size 11, Times New roman)

The global transition toward sustainable energy has positioned lithium-ion (Li-ion) batteries as the cornerstone of modern technological advancement, powering everything from portable electronics to the burgeoning electric vehicle (EV) market. As the demand for high-density energy storage grows, the manufacturing processes used to assemble these power

cells must evolve to ensure safety, reliability, and scalability. A critical bottleneck in battery pack assembly is the joining of individual cells, typically 18650 cylindrical cells, into larger modules using sheet metal connectors. Traditional manual resistance spot welding, while functional, is fraught with inconsistencies such as varying weld strength, excessive heat generation that can damage cell chemistry, and low throughput. These manual limitations not only increase the risk of thermal runaway in high-capacity packs but also inflate labour costs and material waste, making them increasingly incompatible with the rigorous standards of Industry 4.0. Consequently, there is a pressing industrial need for automated solutions that can deliver precise, repeatable, and high-quality electrical connections without compromising the structural integrity of the battery.

Global demand for lithium-ion batteries will be over 3,100 GWh in 2030

Market demand for LIB by application [in GWh]



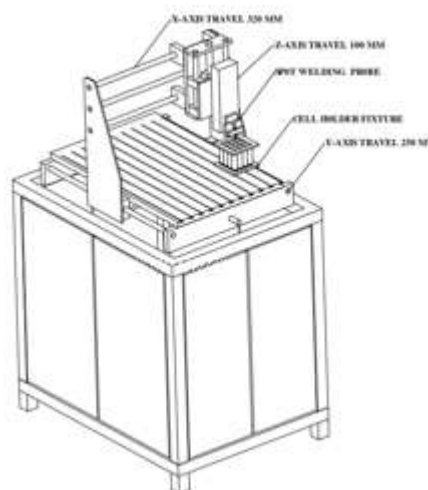
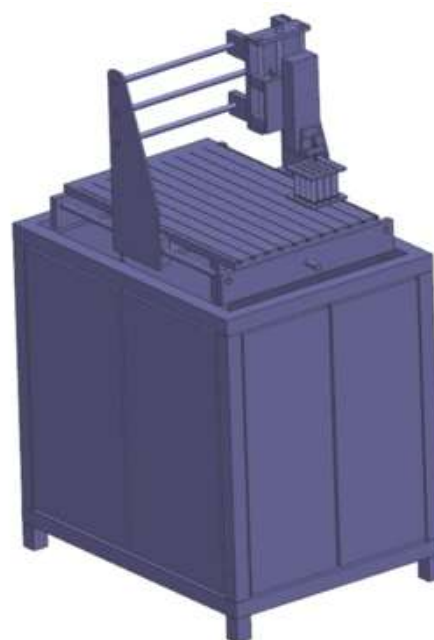
This project addresses these manufacturing challenges through the design and implementation of an automated three-degree-of-freedom (3-DOF) spot welding system. Controlled by an Arduino microcontroller, this robotic architecture allows for the precise positioning of welding electrodes across a predefined grid, ensuring that each cell-to-connector joint is uniform in both geometry and conductivity. The shift toward automation is not merely a matter of mechanical movement but involves the sophisticated integration of hardware and software to manage complex variables. By automating the welding cycle, the system mitigates human error and provides a stable platform for high-volume production, potentially increasing monthly output from 300 to 350 units while

simultaneously lowering variable costs. The project serves as a comprehensive bridge between theoretical engineering design and practical industrial application, focusing on how precision motion control can optimize the assembly line for sensitive electronic components.

To ensure the success of this automated system, a deep dive into the physics of the welding process is essential. This research incorporates detailed 3D Finite Element (FE) simulations to analyse the thermomechanical behaviour of the materials during the welding pulse. By studying parameters such as electrode tip geometry, welding force, supply voltage, and electrode spacing, the project identifies the "sweet spot" for achieving maximum nugget strength while minimizing the heat-affected zone. These simulations are crucial for predicting electric current distribution and potential material deformation before a single weld is even struck. By validating these computational models with experimental data, the project establishes a robust framework for optimizing the spot-welding process. Ultimately, this work contributes to the development of more durable and efficient battery packs, providing a scalable blueprint for the future of automated energy storage manufacturing.

The production of the battery has increased from 300 to 350 per month in 2 shifts of working. Saving from lesser consumption of the consumables is Rs. 750/- per job. Deducting the manpower expenses and price discount to the clients the net benefit to the company is Rs. 2.75 Lakh per month or Rs. 32 Lakh per year. The project is implemented in the month of April 2026 and production with increased demand has started from June 2026.

2. METHODOLOGY: A parameter study is done to evaluate the most crucial parameters for FE analysis of axial ball bearings. The parameters that are evaluated are mesh density, contact stiffness, osculation, load level, geometrical nonlinearity and material nonlinearity. The studies are performed by means of the FE software Ansys. The accuracy of finite element analysis depends on different parameters such as element type, boundary condition and how the loads are applied etc. Therefore, the FE model is nothing else but an approximate realization of the reality. The parameter study can be done by physical tests. However, it will increase the cost, time and resources consumed and therefore FE analysis is more suitable choice, at least for parameter evaluation.



2. PROBLEM:

The manufacturing of high-capacity lithium-ion battery packs for electric vehicles and portable electronics faces a critical bottleneck in the assembly of 18650 cylindrical cells using sheet metal connectors. Current manual resistance spot welding techniques are inherently problematic due to a lack of precision and repeatability, leading to inconsistent joint quality that can compromise the electrical and mechanical integrity of the entire power system. Human operators often struggle to maintain uniform electrode pressure and precise positioning, resulting in varying weld nugget sizes and potentially excessive heat generation. This localized overheating is particularly hazardous for lithium-ion chemistry, as it increases the risk of damaging internal cell components or triggering thermal runaway. Furthermore, manual processes suffer from low productivity rates and high labor costs, making it difficult for manufacturers to scale production to meet rising global demands. The absence of standardized welding parameters—such as optimized supply voltage, welding time, and electrode force—often leads to

material waste and frequent rework. Consequently, there is an urgent need for an automated, three-degree-of-freedom (3-DOF) welding system that utilizes microcontroller-based motion control and optimized parameter settings to ensure safety, enhance throughput, and achieve the rigorous quality standards required for modern energy storage applications.

3. CONCLUSIONS

The development of the CNC Special Purpose Machine (SPM) for lithium-ion battery spot welding represents a significant leap in manufacturing efficiency and product reliability for the electric vehicle (EV) sector. This project successfully addressed the critical bottleneck in battery pack assembly by transitioning from manual, labour-intensive soldering and welding processes to an automated 3-axis CNC system. The study conclusively demonstrated that the implementation of automation not only scales production but also fundamentally improves the electrical and mechanical integrity of the battery connections.

A primary achievement of this work was the optimization of welding parameters, including electrode tip geometry, welding force, and current timing, which were validated through both finite element analysis (FEA) in Ansys and physical experimentation. The analysis revealed that manual wire soldering often led to heat generation issues and localized resistance, which negatively impacted battery performance. By adopting CNC-controlled spot welding with copper or nickel strips, the company achieved higher conductivity, leading to faster charging rates and improved discharge performance.

Future iterations could explore the integration of Laser Beam Welding (LBW) or Ultrasonic Metal Welding (UMW). While resistance spot welding is cost-effective, LBW offers a more concentrated heat source with smaller spot sizes, which can further reduce the heat-affected zone and prevent potential damage to sensitive battery chemistry. Similarly, UMW is a solid-state process that could eliminate melting altogether, providing excellent bonds for thin foils and multi-layered connectors

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