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FACULTY OF ENGINEERING

Design and manufacturing of a spot welding machine

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GRADUATION PROJECT REPORT

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ABSTRACT

Design and manufacturing of a spot welding machine

It is aimed to design a small spot welding machine which could be a desktop device. It should be used to weld the sheets at different thickness and also be safe so control part of the system should also be considered in design. Later designed machine will be manufactured and be tested.

SYMBOLS

Symbol	Definition	Unit
Q	Generated heat energy	Joule (J)
I	Electric current	Ampere (A)
R	Electrical resistance	Ohm (Ω)
t	Time duration of current application	Second (s)
P	Power	Watt (W)
V	Voltage	Volt (V)
η	Welding efficiency	– (dimensionless)
F	Electrode force	Newton (N)
A	Contact area between electrode and material	Square meter (m^2)
P	Electrode pressure	Pascal (Pa)
d	Nugget (weld core) diameter	Millimeter (mm)
k	Material-dependent coefficient for nugget size	– (dimensionless)
N	Number of cycles	–
f	Power supply frequency	Hertz (Hz)

ABBREVIATIONS

Abbreviation	Definition
AC	Alternating Current
ADC	Analog-to-Digital Converter
ANN	Artificial Neural Network
DAC	Digital-to-Analog Converter
DC	Direct Current
HMI	Human-Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
IGBT	Insulated Gate Bipolar Transistor
LED	Light Emitting Diode
MOT	Microwave Oven Transformer
NDT	Non-Destructive Testing
PID	Proportional-Integral-Derivative (control system)
PLC	Programmable Logic Controller
SDG	Sustainable Development Goals
TTR	Twin-Twin Round (Cable Type)

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1. INTRODUCTION

Spot welding, one of the oldest and most widely used resistance welding methods, is a process that combines heat and pressure to join two or more metal sheets without the need for filler materials. The underlying principle of spot welding is based on electrical resistance and the Joule heating effect, where an electric current is passed through the contact points of the metal sheets. This generates localized heat, which melts the metal and allows it to fuse under the pressure applied by copper alloy electrodes.

The process is governed by Ohm's Law and the equation for heat generation, $Q=I^2Rt$, where:

- Q represents the heat energy,
- I is the current,
- R is the electrical resistance, and
- t is the duration of current flow.

This theoretical framework emphasizes the importance of balancing key parameters such as current intensity, resistance, and time to achieve a consistent and durable weld. The choice of electrode material, typically copper alloys, also plays a critical role in optimizing heat transfer and minimizing thermal losses.

Spot welding is particularly effective for thin metal sheets and is widely used in industries such as automotive manufacturing, electronics, and home appliances. Its efficiency, speed, and ability to produce high-strength joints make it indispensable for mass production. However, achieving optimal results requires careful consideration of material properties, welding conditions, and machine design, all of which are analyzed in detail within this study.

By delving into the theoretical aspects of spot welding, this section lays the foundation for understanding the design and operational principles of the spot welding machine developed in this project.

1.1. Purpose and Scope of the Thesis

The purpose of this thesis is to design and analyze a spot welding machine suitable for industrial applications, specifically focusing on its functionality, efficiency, and performance. Spot welding is a widely used technique in industries such as automotive manufacturing, home appliances, and electronics due to its cost-effectiveness, speed, and reliability.

The scope of this study includes the following:

- Understanding the principles and working mechanism of spot welding.
- Designing a spot welding machine tailored to industrial requirements.
- Analyzing the machine's performance across different materials and thicknesses.

- Evaluating the mechanical strength, durability, and energy consumption of the welds produced.

- Addressing practical challenges in the design and production process, while keeping cost-efficiency in focus.

By the end of this thesis, a comprehensive understanding of spot welding technology will be achieved, supported by both theoretical analysis and experimental studies.

1.2. What is a Spot Welding Machine?

A spot welding machine is a type of resistance welding equipment designed to join two or more overlapping metal sheets without the use of filler materials. The process involves applying pressure and heat to the welding area using copper alloy electrodes and a high electrical current. The heat generated at the point of contact melts the metals, which are then fused together under pressure.

Spot welding machines are categorized into different types based on their application and design:

1.2.1. Handheld Spot Welding Machines:

Portable devices offering flexibility for non-robotic manufacturing.

1.2.2. Footed Spot Welding Machines:

Commonly used in small to medium-sized workshops.

1.2.3. Robotic Spot Welding Machines:

Widely utilized in automated processes, particularly in the automotive industry.

These machines are favored for their ability to produce high-strength welds quickly and efficiently, making them a staple in industries requiring mass production of metal components.

1.3. History and Development of Welding Technologies

Welding has been an integral part of metal fabrication since the early 20th century. Spot welding, in particular, is one of the oldest and most commonly used welding techniques. Its development can be traced back to the introduction of resistance welding technologies in the early 1900s.

Key milestones in the development of welding technologies include:

- 1900s: The emergence of resistance welding methods, including spot welding, as alternatives to traditional riveting and bolting.

- 1930s-1950s: The automotive industry adopted spot welding for mass production of car bodies, significantly reducing production time and costs.

- 1980s: Advancements in control systems allowed for precise timing and current regulation, improving the quality and consistency of spot welds.

- 2000s and Beyond: Integration of robotic systems and automation enhanced the efficiency and scalability of spot welding, making it a cornerstone of modern manufacturing.

Today, spot welding remains a preferred choice due to its simplicity, cost-effectiveness, and adaptability to automated production lines.

1.4. Significance and Objectives of the Study

Spot welding plays a critical role in the manufacturing of thin-sheet metal components, particularly in the automotive and electronics industries. Its significance lies in its ability to produce reliable joints with minimal material deformation and energy consumption.

The primary objectives of this study are:

- To design a compact and efficient spot welding machine capable of handling various material types and thicknesses.

- To evaluate the performance of the machine in terms of weld quality, durability, and energy efficiency.

- To address limitations in existing spot welding machines, such as high production costs and maintenance challenges.

- To explore innovative solutions for improving the adaptability and functionality of spot welding machines in different industrial contexts.

This study aims to contribute to the field of mechanical engineering by presenting a practical and theoretical framework for the design and optimization of spot welding machines.

1.5. Problem Definition and Limitations of the Study

In today's manufacturing landscape, the demand for affordable, robust, and adaptable welding solutions has increased significantly. However, existing spot welding machines face several challenges:

- **High Costs:** Many industrial-grade machines are expensive, making them inaccessible for smaller-scale manufacturers.

- **Maintenance Issues:** The complexity of some machines results in frequent downtime and high maintenance costs.

- **Material Limitations:** While spot welding is effective for certain metals like steel and aluminum, achieving consistent results with other materials can be difficult.

- **Scalability:** Adapting spot welding machines for custom or low-volume production can be challenging due to their focus on mass production.

This study addresses these limitations by designing a machine that is:

- Cost-efficient and simple to operate.
- Capable of producing high-quality welds across various materials and thicknesses.
- Easy to maintain and integrate into existing production setups.

The primary limitation of this study is its focus on small to medium-scale industrial applications, which may not fully capture the requirements of large-scale manufacturing environments. Additionally, the experimental analysis will primarily be conducted on commonly used metals such as steel and aluminum, potentially limiting its applicability to other materials.

2. LITERATURE REVIEW

The literature review serves as a critical foundation for this thesis by examining existing research, technologies, and standards relevant to spot welding. This section explores the key aspects of spot welding, including its principles, materials, technological advancements, and performance analyses. Furthermore, a comparison of similar machine designs and their innovative features is provided, alongside an overview of industrial standards and practices. By consolidating knowledge from diverse sources, this chapter establishes the theoretical and practical background necessary to inform the design and evaluation of the spot welding machine developed in this study.

2.1. Overview of Spot Welding

Spot welding, a type of resistance welding, is a process where heat and pressure are applied to join two or more overlapping metal sheets at localized points. It is characterized by its simplicity and efficiency, which have made it a cornerstone in industries requiring mass production, such as automotive manufacturing and electronics. Unlike fusion welding techniques, spot welding does not require filler materials, relying instead on the resistance of the materials and the electric current to generate the heat necessary for welding.

The process is governed by Ohm's Law and the equation for heat generation, $Q=I^2Rt$, where:

- Q represents the heat energy,
- I is the current,
- R is the electrical resistance, and
- t is the duration of current flow.

This localized heating ensures that the thermal energy is confined to the immediate weld area, preventing deformation in adjacent material. Additionally, the process is rapid, with typical weld times measured in milliseconds. Its widespread adoption in the automotive sector, where up to 5,000 spot welds are used in a single vehicle, underscores its importance in modern manufacturing

2.2. Materials Used in Welding Technologies

The effectiveness of spot welding largely depends on the properties of the materials being joined. Common materials used in spot welding include:

2.2.1. Steel (Low Carbon and High Carbon):

- Low Carbon Steel: Ideal for spot welding due to its low electrical resistance and high weldability.

- High Carbon Steel: Prone to cracking and brittleness due to the formation of hard microstructures during welding, necessitating controlled heat input.

2.2.2. Galvanized Steel:

- Zinc coating on galvanized steel requires higher welding currents and frequent electrode maintenance to counteract contamination.

- Electrode dressing or replacement is often needed to ensure consistent weld quality.

2.2.3. Aluminum:

- Aluminum poses challenges due to its high thermal conductivity and low electrical resistance, requiring 2-3 times more current than steel for effective welding.

2.2.4. Copper and Alloys:

- While copper's low resistance makes it less suitable for spot welding with standard electrodes, specialized materials like molybdenum and tungsten are used for welding copper.

- The selection of materials must also account for factors such as thermal conductivity, electrical resistance, and melting point, all of which significantly influence the quality and strength of the weld.

3. Clarifiying Objectives

Designing typically begins with a need or a challenge, which may originate from an industrial requirement, an engineering goal, or a desire to improve an existing process. The first step is to determine the problem that will be solved and to define the requirements accordingly. The "objective tree" method helps to identify these requirements by asking "how" questions, starting from general goals and breaking them down into more specific, actionable items.

Before creating the objective tree, we must first define the scope of the project. In our case, the chosen product is a **Spot Welding Machine**. Spot welding machines are used in various industries, including automotive, appliance manufacturing, and metal fabrication, where strong and rapid welds are essential for joining sheet metal parts. The design and performance of the machine are influenced by factors such as the type of material to be welded, current and voltage requirements, cycle time, and user safety.

3.1. Safety

In any electrical or welding application, safety is a critical concern. Spot welding involves high electrical currents and intense localized heating, both of which can pose serious hazards to the operator and the environment. Therefore, the first branch of our objective tree is safety.

To ensure operator safety, we must ask, *"What needs to be protected, and how?"* The user should be protected from electrical shocks, high temperatures, accidental short circuits, and pinch points. Proper insulation, grounding, and circuit protection must be implemented. Additionally, safety mechanisms such as emergency stop buttons, heat-resistant handles, and physical shielding should be included in the design. Environmental safety must also be considered—ensuring the machine does not release harmful fumes, excessive noise, or radiation.

3.2. Cost Effectiveness

A product's market success largely depends on its affordability. Thus, the second branch of our objective tree is cost effectıveness. To be cost-effective, a spot welding machine must balance performance with affordability. The design should minimize material costs without sacrificing durability or function. We must also ensure that spare parts, such as electrodes or switches, are easy to obtain and replace. Maintenance procedures should be simple, and component lifespans should be long to reduce repair frequency. Choosing commonly available and reasonably priced components will enhance economic feasibility.

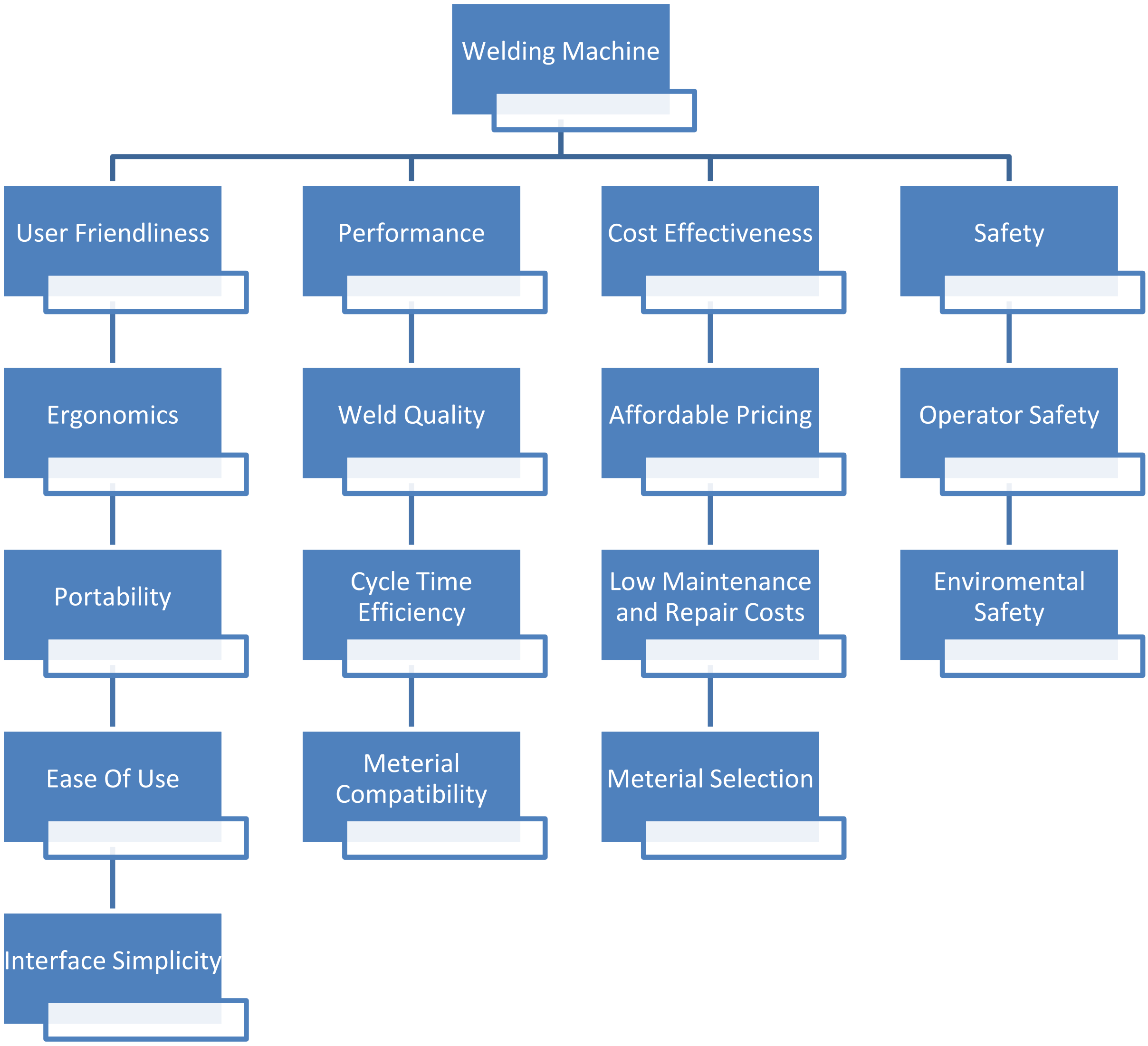
3.3. User Friendliness

Another key design objective is user friendliness. A user-friendly spot welding machine should be easy to operate, adjust, and maintain—even by inexperienced users. The control interface must be intuitive, possibly with clear buttons or a display indicating weld parameters. Setup and usage instructions should be straightforward, and component access should be convenient for cleaning or repairs. The machine should be portable or compact enough to fit into different workshop layouts, depending on the intended application.

3.4. Performance (Welding Quality & Efficiency)

In addition to the previous branches, performance is an essential part of our objective tree. A spot welding machine must deliver consistent, high-quality welds across various metals and thicknesses. This requires a reliable current delivery system, proper electrode force, and precise timing. Welding cycle time should be optimized for productivity, especially in industrial applications. The machine should be capable of handling the desired material range (e.g., mild steel 1 mm thickness) without defects such as expulsion, porosity, or insufficient bonding.

By focusing on these four core branches—Safety, Cost Effectiveness, User Friendliness, and Performance—we aim to develop a spot welding machine that meets user needs while ensuring a safe, reliable, and economically viable solution.



By focusing on these four core branches—Safety, Cost Effectiveness, User Friendliness, and Performance—we aim to develop a spot welding machine that meets user needs while ensuring a safe, reliable, and economically viable solution.

4. Establishing Functions

Every engineering system is built upon a set of functions and sub-functions that work together to fulfill its purpose. Identifying these functions accurately ensures that the machine operates correctly and safely. In this section, we use the functional analysis method to break down the sub-processes of our Spot Welding Machine step by step.

We consider the Spot Welding Machine as a black box system. From the user's perspective, the machine creates a weld when the operator brings two metal sheets between the electrodes and activates the device. Internally, however, several mechanical and electrical functions occur to ensure a proper spot weld.

In our system, we repurposed a microwave oven transformer as the heart of the machine.

The primary (high-voltage) coil of the transformer was carefully removed, and instead, we wound several turns of 10 mm^2 thick copper wire onto the core to create a low-voltage, high-current secondary winding. This winding is capable of delivering several hundred to over a thousand amperes of current at a low voltage, which is ideal for resistance spot welding.

The ends of the copper wire are then connected to the upper and lower arms of the welding machine. At the tips of these arms, we installed solid copper pins (electrodes) which contact the metal sheets. When the user activates the machine (via a button or switch), the transformer energizes the secondary circuit, and current flows through the metal sheets, generating enough resistance heat to locally melt and fuse them under pressure.

Once the weld is complete, the current stops, and the metal cools rapidly, forming a solid welded joint.

4.1. Main Functions of the Spot Welding Machine

4.1.1. Power Input & Conversion

- The machine operates using a 220V AC power supply.
- A transformer taken from a microwave oven is used.
- The secondary winding of the transformer is completely removed, leaving only the primary winding intact.

4.1.2. Secondary Coil Construction

- Several turns of 10 mm^2 thick multi-stranded copper cable are manually wound around the transformer core.
- This new winding is designed to deliver low voltage and high current suitable for spot welding.

4.1.3. Current Delivery to Electrodes

- The ends of the copper cable are routed to the upper and lower arms of the welding machine.
- Copper pins (electrodes) installed at the tips of these arms deliver the welding current directly to the metal sheets.

4.1.4. Contact and Pressure Mechanism

- The user places two overlapping metal sheets between the upper and lower electrodes.
- The arms are aligned to apply pressure at the welding point.

4.1.5. Welding (Spot Creation)

- When the user activates the switch, current flows through the secondary winding and is delivered to the electrodes.
- The high current generates localized resistance heating, causing the metal to melt and fuse at the contact point.

4.1.6. Cooling and Finalization

- Once the current stops, the molten metal cools rapidly and solidifies, forming a permanent weld.
- After the process, the user can remove the welded parts and proceed with the next operation.

5. Setting Requirements

We have established the objectives and functions that the spot welding machine must achieve. However, defining goals such as "safe" or "high performance" alone is not sufficient—clear, measurable performance requirements are essential. These requirements provide the technical limits and quality thresholds that the design must meet to be functional, safe, and competitive.

To define these specifications, we examine user needs, existing industry standards, and feedback gathered from testing and usage observations. Since the spot welding machine operates with high electrical currents and mechanical pressure, performance criteria must address safety, durability, efficiency, and usability.

Unlike typical consumer products, a spot welding machine must meet essential engineering constraints such as safe current levels, effective heat generation, stable electrode pressure, and reliable weld quality. For example, the machine should be capable of delivering a short burst of at least 1000 A current, while maintaining an output voltage below 3V. It must also withstand repeated welding operations without overheating or degrading component performance.

Other considerations include the durability of the copper electrodes, proper insulation and grounding of the transformer, and the stability of the mechanical structure. Additionally, user-friendly design such as accessible electrode mounting and a clearly marked on/off switch enhances operability and reduces the risk of error during welding.

5.1. Performance Specification Method

Performance requirements are derived from technical analysis and user expectations. In the case of our spot welding machine, this process included evaluating the transformer's capacity, conducting current flow tests, and observing weld quality across different materials.

Key requirements include:

- **Electrical safety** (proper insulation, fuses, grounding),

- **Thermal endurance** (cooling system, heat-resistant materials),
- **Mechanical reliability** (firm mounting of electrodes, stable frame),
- **Operational simplicity** (single-button operation, status indication),
- **Weld quality consistency** (repeatable results under fixed parameters).

By specifying these requirements with defined tolerances, we ensure that the spot welding machine can perform safely and effectively under expected working conditions.

Specification Table for Spot Welding Machine

Specification for Hand-Held Circular Saw		
Changes	D or W	**Requirements**
	D	Max output voltage: < 3 V (AC)
	D	Welding current capacity: ≥ 1000 A
	D	Electrical insulation around transformer and wiring
	D	Integration of fuse or circuit breaker for overcurrent protection
	W	Emergency shut-off button for user safety
	D	Secure mounting of transformer and electrodes
	W	Use of copper pins as durable electrodes
	D	Transformer secondary coil: thick copper cable (10 mm^2)
	D	Transformer should not exceed 60°C surface temperature during repeated use
	W	External casing (wood or metal) to prevent accidental contact

D	Weld time control: 0.5–1.5 seconds cycle duration
W	Cooling solution (fan or ventilation holes)
D	Electrodes must provide firm and stable contact with metal pieces
W	Design must allow easy access for electrode replacement
D	Machine must successfully weld 1 mm low carbon steel sheets
W	System must be usable by a single operator with minimal training

Tablo 1 D/W table for spot welding

6. Determining characteristics

In the development of a spot welding machine, different stakeholders—including engineers, users, and academic evaluators—may have diverse priorities. While users are mainly concerned with safety, ease of operation, and portability, engineers focus on performance-related parameters such as weld quality, current flow reliability, and thermal management.

To connect user expectations with measurable engineering requirements, we applied the House of Quality (HoQ) method. This tool allows us to analyze which technical features (HOWs) most directly address key user needs (WHATs). By building a correlation matrix, we can prioritize design decisions and evaluate trade-offs.

For example, the user need *"safe operation"* can be addressed through engineering characteristics such as *electrical insulation*, *overcurrent protection*, and *thermal shielding*. Similarly, the user expectation of *"consistent weld quality"* depends on technical aspects like *electrode force stability*, *current amplitude*, and *material compatibility*. The stronger the correlation between a user requirement and an engineering characteristic, the higher its design priority.

This method helps us design a spot welding machine that not only meets functional performance goals but also satisfies user expectations, ensuring usability, safety, and efficiency across various working conditions.

Figure 1 House of Quality

7. Similar Machine Designs and Innovations

Spot welding machines have evolved significantly to meet the demands of modern manufacturing. These machines can be categorized into three main types:

- **Handheld Spot Welding Machines:** Portable and flexible, ideal for small-scale applications.
- **Footed Spot Welding Machines:** Frequently used in small to medium-sized businesses, offering enhanced stability and control.
- **Robotic Spot Welding Machines:** Predominantly used in the automotive industry, these machines are integrated into automated production lines for high-speed and high-precision welding.

Innovations in machine design have focused on enhancing efficiency, reliability, and adaptability. For instance:

- **Advanced Control Systems:** Microcontroller-based systems enable precise timing and current regulation, improving weld consistency.
- **Cooling Mechanisms:** Water-cooled electrodes extend machine longevity and reduce overheating risks.
- **Compact Designs:** Machines optimized for limited workshop spaces while maintaining industrial-grade performance.

These advancements underline the importance of integrating cutting-edge technologies into spot welding machines to meet the diverse needs of industries

8. Studies on Mechanical and Electrical Performance of Welding

The performance of spot welding is influenced by several factors, including:

8.1. Current Intensity:

Higher currents generate sufficient heat but must be carefully controlled to prevent material distortion.

8.2. Pressure:

Proper electrode pressure ensures optimal contact and prevents air gaps, which can weaken the weld.

8.3. Heat Distribution:

Uniform heat distribution across the weld area is critical for producing durable joints.

Studies have demonstrated that mechanical properties such as tensile strength and fatigue resistance are directly correlated with the welding parameters. Additionally, the electrical efficiency of spot welding machines is a key area of research, with efforts focused on minimizing energy consumption without compromising weld quality. These findings highlight the need for meticulous parameter optimization in spot welding applications

9. Industrial Standards and Current Practices

Spot welding practices are governed by industry standards to ensure consistency, safety, and quality. Key standards include:

- ISO 14373: Specifications for resistance spot welding of metallic materials.
- AWS D8.1M: Automotive welding guidelines outlining best practices for spot welding in vehicle manufacturing.

Current practices emphasize the following:

- Automation: Robotic systems are increasingly being adopted for spot welding in high-volume production environments.
- Quality Assurance: Techniques such as non-destructive testing (NDT) are used to evaluate weld quality without damaging the material.
- Sustainability: Efforts to reduce energy consumption and electrode waste reflect a growing focus on environmentally friendly manufacturing processes.
- The adherence to these standards and practices ensures that spot welding remains a reliable and efficient method for joining thin metal sheets.

10. Equation

10.1. Heat (Energy) Equation

$$Q = I^2 * R * t$$

Q = Generated heat energy (Joule or Watt-second)

I = Source current (Amperes)

R = Electrical resistance (Ohms)

t = Duration of current application (seconds)

The current (I) directly affects the generated heat and is proportional to its square. This indicates that small changes in current can lead to significant changes in heat production.

The resistance (R) represents the total electrical resistance at the source. The highest resistance during welding usually occurs at the contact region between the two metal surfaces. Factors such as material conductivity, surface cleanliness, and electrode pressure influence the resistance value.

The time (t) determines how long the current is applied. Very short durations result in insufficient welding, while excessively long durations generate too much heat, potentially damaging the material.

This equation is derived from Joule's Law and forms the fundamental principle of energy generation in spot welding.

10.2. Electrode Pressure Equation

$$F = P * A$$

F = Total force applied by the electrodes (Newton)

P = Electrode pressure (Pascal)

A = Contact area between electrodes and material (m^2)

Higher pressure reduces contact resistance, thereby decreasing heat generation. If the contact resistance is too low, insufficient heat is produced, reducing weld quality.

Lower pressure increases contact resistance, leading to higher heat generation. However, if the pressure is too low, arcing may occur, causing welding defects.

The contact area (A) depends on the diameter and shape of the electrode tip. Smaller electrode tips generate higher pressure and create a more focused weld zone.

Thus, proper electrode pressure adjustment is a crucial factor in determining the quality of spot welding.

10.3. Nugget (Weld Core) Diameter Equation

$$d = k * \sqrt{t}$$

d = Nugget diameter (mm)

k = Coefficient dependent on material and welding conditions

t = Material thickness (mm)

The nugget diameter is essential for weld strength. If the nugget diameter is too small, the weld may be weak; if it is too large, excessive heating can damage the material.

Material thickness directly affects the nugget diameter. Thicker materials require larger nugget diameters.

The coefficient (k) depends on the type of metal used, current level, pressure, and electrode geometry. For steels, k typically ranges between 4 and 6.

This formula is used to estimate the nugget diameter, but the actual size may vary depending on the welding parameters.

10.4. Power Equation

$$P = V * I * \eta$$

P = Instantaneous power (Watts)

V = Applied voltage (Volts)

I = Welding current (Amperes)

η = Welding efficiency (typically between 0.7 - 0.9)

Power determines the instantaneous energy consumption during welding. Higher power levels produce more heat and enable faster welding.

Voltage (V) in spot welding is generally kept low, typically in the range of 3-15V.

Efficiency (η) accounts for heat losses and represents actual power usage. Since some heat is dissipated into the surroundings, achieving 100% efficiency in welding is impossible.

This equation is essential for understanding the total energy consumption of a welding machine.

10.5. Welding Time and Frequency Equation

$$t = \frac{N}{f}$$

t = Welding time (seconds)

N = Number of applied cycles

f = Power supply frequency (Hz)

The power supply frequency (f) is typically 50 Hz (Europe) or 60 Hz (USA).

Longer cycle durations lead to higher heat generation and increase the nugget size.

This equation ensures the correct adjustment of welding time, which is crucial for achieving optimal weld quality.

3. COMPONENTS OF THE SPOT WELDING MACHINE

3.1. Design Requirements

The design of a resistance spot welding machine requires careful consideration of multiple factors, including electrical performance, thermal behavior, mechanical structure, usability, and safety. Unlike industrial-grade systems, this project aimed to develop a cost-effective, compact, and user-friendly spot welding machine using mostly readily available or recycled components—particularly focusing on repurposing a microwave oven transformer (MOT).

To ensure the machine met both functional and safety expectations, a set of design requirements was established early in the development process. These requirements were shaped by the physical limitations of the selected components, user needs, engineering constraints, and standard practices in resistance welding.

3.1.1. Electrical Performance

The system had to deliver a high current (700–800 A) at a low voltage (2–4 V), sufficient for welding 1 mm thick low-carbon steel sheets.

A repurposed MOT was used, with its secondary coil removed and replaced by custom-wound 10 mm^2 copper cable to generate the necessary current without overheating.

All wiring had to be sized and protected appropriately to withstand high current with minimal losses and no risk of short circuits.

3.1.2. Mechanical Structure

The machine's body had to provide a stable and vibration-free platform for welding operations.

A wooden frame was chosen for its ease of fabrication, non-conductive properties, and cost-effectiveness.

The design required precise alignment of the upper and lower electrodes, which was achieved through fixed arm geometry and spring-loaded movement mechanisms.

3.1.3. Thermal Management

Given the high currents involved, proper cooling was essential to prevent damage to the transformer and wiring.

A 120 mm DC fan, powered by an AC–DC adapter, was integrated to ensure continuous airflow over heat-sensitive components.

The internal layout of components was planned to allow airflow circulation and minimize heat concentration.

3.1.4. Electrode Design

The electrodes had to maintain firm contact with the workpieces and provide consistent current flow during each weld cycle.

Custom-fabricated copper pins (4.5 mm diameter) were used as electrodes due to their excellent electrical and thermal conductivity.

Electrodes were mounted into square aluminum blocks, which were then securely attached to the wooden arms for precise and repeatable contact.

3.1.5. Control and Usability

A push-button switch was placed on the upper arm, enabling the operator to activate the weld current manually while applying pressure.

A light indicator, toggle switch, and circuit breaker were included for system control, safety feedback, and protection.

All components had to be accessible and maintainable by the user, encouraging modularity in design.

3.1.6. Safety and Protection

The entire transformer and wiring area was enclosed with plexiglass panels to prevent accidental contact with live components.

All cable joints were soldered and insulated with heat-shrink tubing, and wires were fixed using cable holders to prevent movement or wear.

A grounding system was included to ensure operator safety in the event of a fault.

3.1.7. Material and Cost Constraints

The machine had to be built with affordable and available materials, often using recycled components such as a used MOT and scrap wood or plexiglass.

Despite the low budget, the design had to replicate the functional core of a professional spot welding system.

In summary, the design requirements for this spot welding machine aimed to balance performance, safety, usability, and affordability. The final design reflects a successful integration of electrical and mechanical systems into a compact and functional prototype that meets the essential criteria for small-scale resistance spot welding.

3.2. Body Design

The structural body of the spot welding machine was designed to be simple, robust, and easy to manufacture using accessible materials. The main framework consists of three custom-cut wooden pieces: a base plate, a vertical support arm, and a connection block. These parts were shaped using basic woodworking tools and securely joined together with screws and metal brackets to provide stability during operation.

Figure 2 body parts made of wood

Wood was selected as the primary body material due to its ease of machining, cost-effectiveness, and its ability to provide a non-conductive mounting platform for high-voltage components. The vertical wooden support holds the upper electrode mechanism, while the base section houses the transformer and other electrical components.

To ensure user safety and cable protection, the backside of the machine was enclosed using green acrylic (plexiglass) panels. These panels were cut to size and fixed with bolts, covering the internal wiring and transformer section. This design not only improves aesthetic appearance but also reduces the risk of accidental contact with live components.

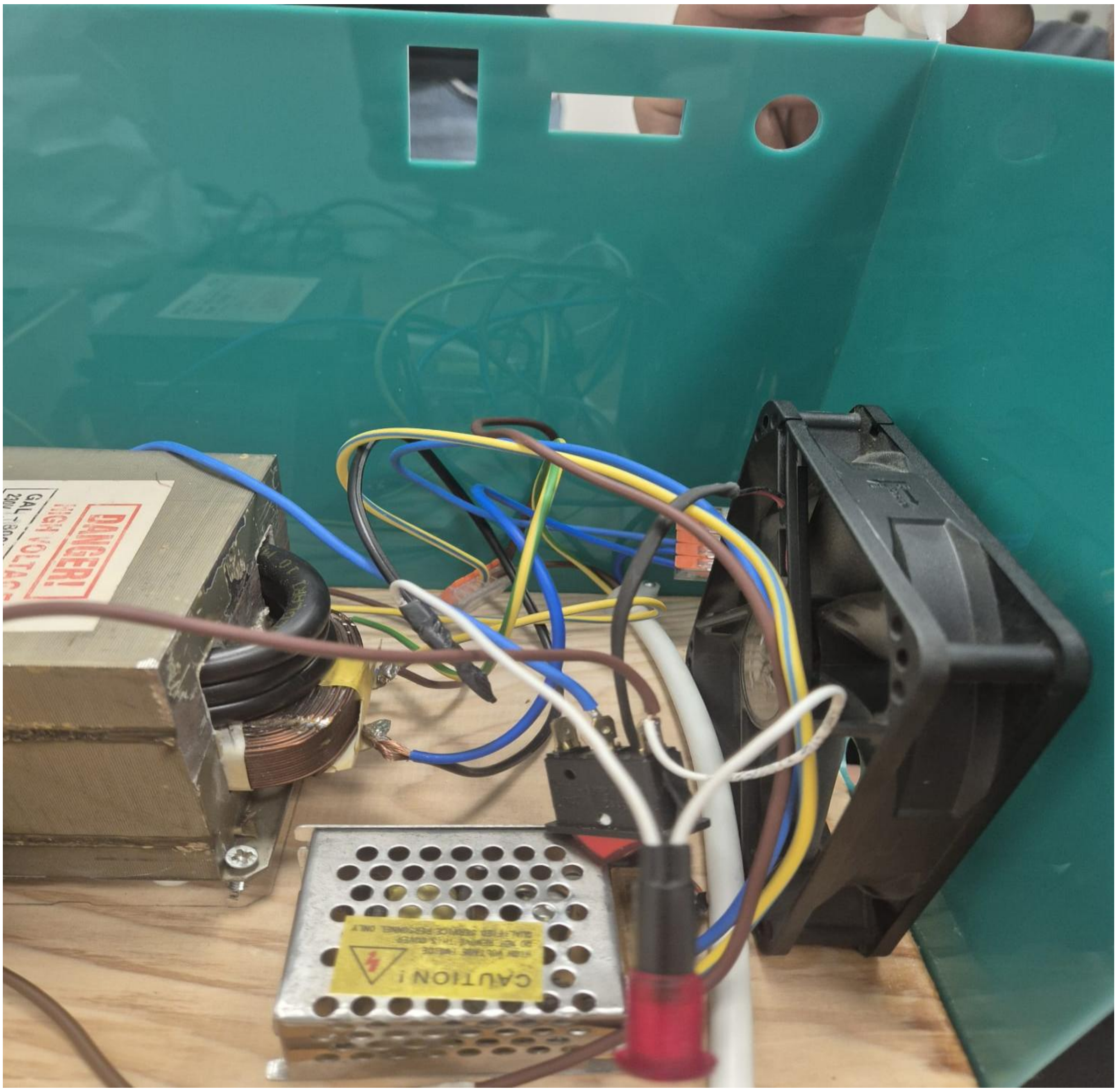


Figure 3

The modular and open nature of the wooden frame also facilitates **easy maintenance**, allowing users to access and modify internal parts when necessary. Overall, the body design successfully balances structural integrity, electrical insulation, and functional simplicity.

3.3. Electrode Design and Material Selection

In resistance spot welding systems, electrode selection is one of the most critical design decisions, as it directly affects current delivery, heat generation, and overall weld quality. For this project, two solid copper pins were selected and custom-fabricated to serve as the upper and lower electrodes of the spot welding machine.

Initially, raw cylindrical copper rods were procured, each with a diameter of 4.5 mm. Copper was chosen due to its excellent electrical and thermal conductivity, mechanical strength, and proven effectiveness in resistance welding applications. The rods were measured, cut to equal lengths, and then machined into pointed tips to enable localized heating at the contact zone.

To ensure precise alignment and structural stability, each copper electrode was inserted into a dedicated electrode holder station, which was fabricated using a square aluminum block. These aluminum blocks were firmly mounted onto the wooden arms of the machine (both upper and lower) using screws. A small hole was drilled through the blocks to tightly fit the copper pins, and additional bolts were used to secure them in place.

The choice of aluminum as the holder material offered the following benefits:

- Good mechanical strength with low weight
- Sufficient heat resistance for indirect exposure
- Easy machining and integration with the wooden structure

In summary, the electrode design was optimized for:

- High current transfer via copper pins
- Mechanical stability via aluminum holders
- Accurate electrode alignment on both upper and lower arms
- Easy maintenance and part replacement when needed

This careful integration of material and mounting design ensures consistent welding performance and long-term reliability of the electrode system.

Figure 4 copper pins

Figure 5 auxiliary station to which copper pins are attached

Figure 6 aluminum parts to which the cable lug is connected

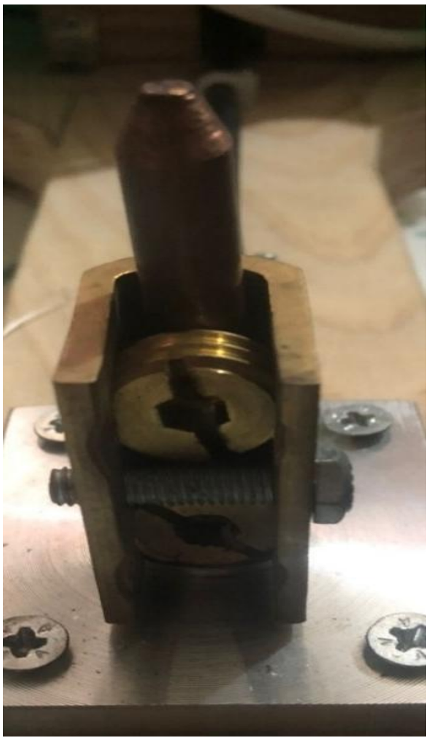


Figure 7 final image after electrode connection is completed

3.4. Power Source and Electrical System

The power source and electrical system are the core elements of a spot welding machine, determining its operational effectiveness, safety, and energy efficiency. In this project, a repurposed 220 V microwave oven transformer (MOT) was used as the primary power supply. To adapt the transformer for high-current, low-voltage output suitable for resistance welding, the secondary coil was fully removed, leaving only the primary winding. In place of the original secondary coil, a custom-wound 10 mm^2 copper cable was tightly wrapped around the transformer core to function as the new secondary.

Figure 8 after removing the primary winding from the transformer

Figure 9 After connecting 10 mm copper cable to the transformer

This setup effectively reduced the output voltage to approximately 2–4 volts, while enabling a high current flow in the range of 700–800 amperes, which is essential for localized resistance heating during spot welding. The large cross-sectional area of the copper cable was carefully selected to minimize resistive losses and handle the high current without overheating.

The electrical circuit also incorporates several safety and control components:

- A light indicator, circuit breaker, and toggle switch were connected in series to allow visual monitoring, short-circuit protection, and manual control of the system.

- A push-button switch was integrated into the upper arm of the machine, allowing the operator to activate the weld current only when proper pressure is applied at the electrodes.

- An external fan, powered through a secondary low-voltage transformer, was added to enhance cooling and prevent overheating of internal components.

- Additionally, grounding was provided to reduce electrical hazard risk and ensure user safety.

To connect the circuit components, 1.5 mm² and 2 mm² copper wires were used selectively based on current load requirements. High-power segments, especially those connected to the transformer secondary and electrodes, were constructed using 10 mm² welding-grade copper cables for durability and safe current conduction.

This thoughtfully designed electrical system provides:

- Reliable current delivery for effective welding

- Controlled and safe operation through layered switching

- Overload protection with circuit breakers

- Thermal management via forced air cooling

By combining a modified microwave transformer with robust wiring and electrical safety components, the power system achieves high-performance spot welding within a compact and cost-efficient design.

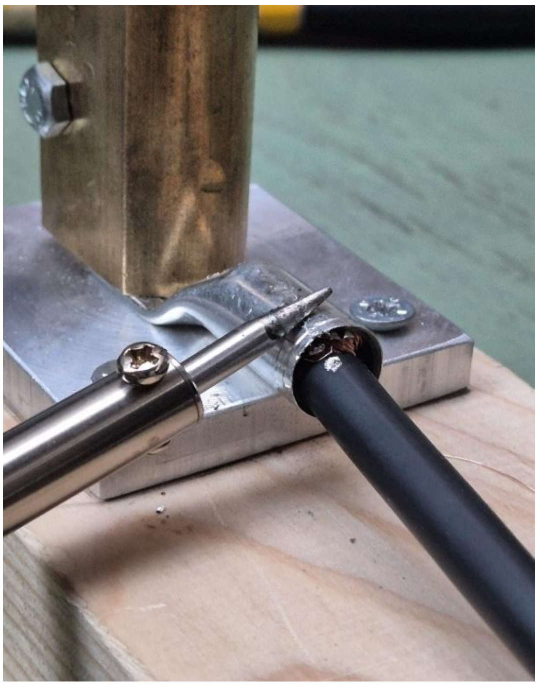


Figure 10 10 mm copper cable soldered to the cable lug with solder.

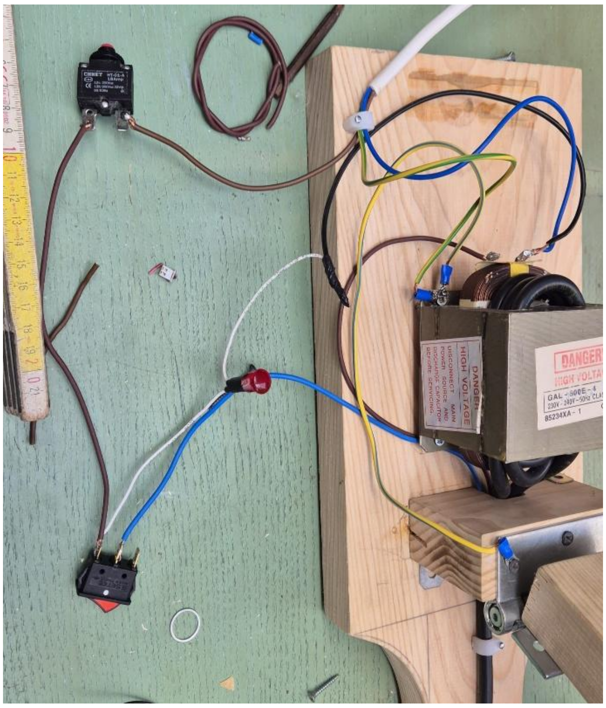


Figure 11 electrical circuit

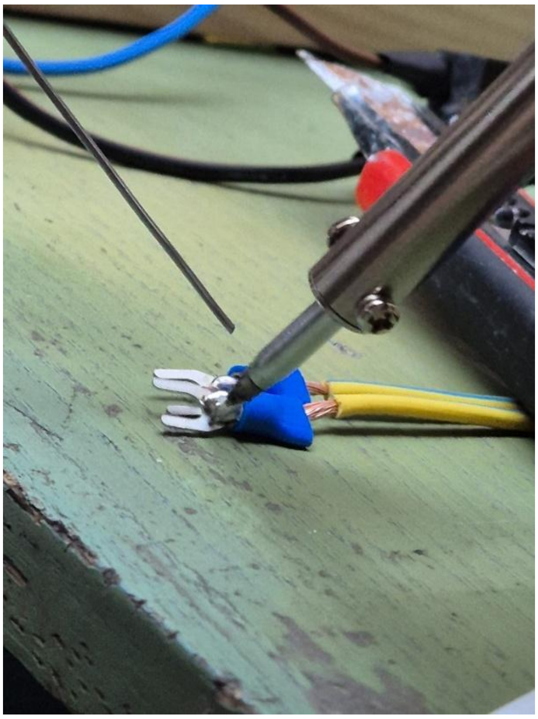


Figure 12 grounding wires

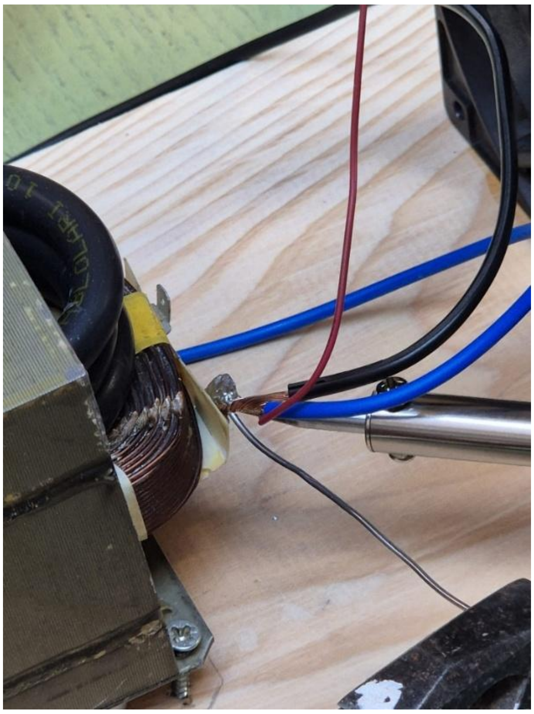


Figure 13 Wires soldered to the neutral part of the transformer

3.5. Cooling System

Effective thermal management is crucial in resistance spot welding systems, where high currents generate considerable localized heat. To ensure both operational safety and component longevity, a cooling mechanism was integrated into the design of our spot welding machine.

A 120 mm computer cooling fan was selected as the primary cooling element due to its compact structure, low power consumption, and adequate airflow capacity. The fan was strategically mounted near the transformer and internal wiring, where heat buildup is most significant during extended operation.

However, since the selected fan operates on DC power, and our machine is primarily powered by an AC source (220 V), an additional component was required to adapt the voltage type. To address this, an AC-to-DC power adapter (voltage converter) was incorporated into the system. This adapter efficiently converts the AC input into the required 12 V DC output, enabling continuous and stable operation of the fan.

The inclusion of the fan and voltage converter in the system provides several key benefits:

- Prevents overheating of the transformer and internal electrical components
- Extends the lifespan of sensitive parts such as wiring insulation and soldered joints
- Improves user safety by reducing the risk of thermal failure or accidental burns
- Supports consistent performance, even during repetitive or prolonged welding cycles

In conclusion, the implementation of an active cooling system using a DC fan and an AC-DC adapter significantly enhances the reliability and efficiency of the spot welding machine. This addition, though simple, ensures thermal control in a cost-effective and compact manner.

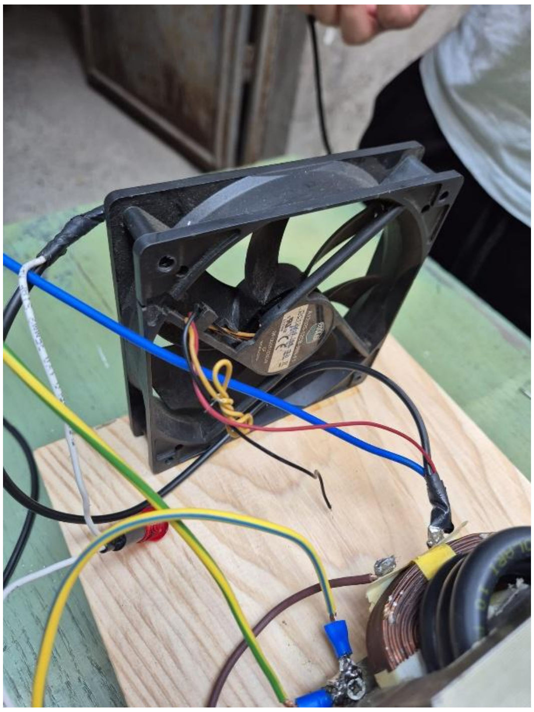


Figure 14 cooling fan

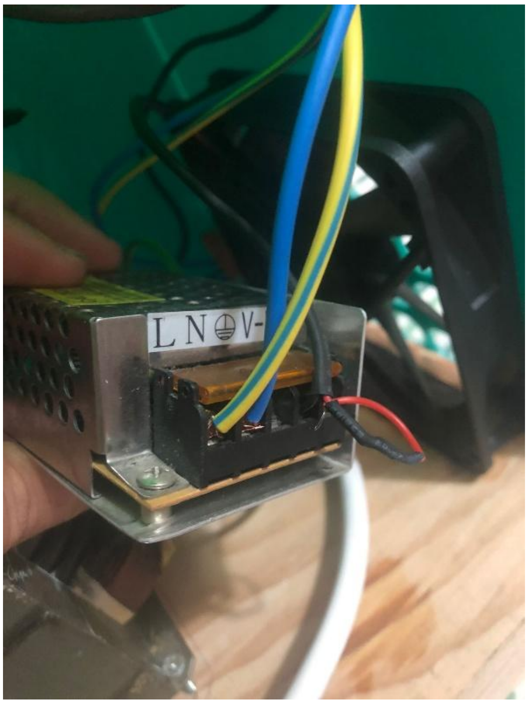


Figure 15 AC-DC converter

3.6. Movement and Mechanical Components

The movement capability of the welding electrode is essential for the functionality of any spot welding machine. In our design, we developed a mechanical movement system that enables the upper electrode to perform smooth and controlled vertical motion, ensuring effective welding operation.

The main motion mechanism is achieved using a spring-loaded hinge, which is mounted between the upper wooden arm and the wooden transition piece (previously shown with a central cable passage hole). This intermediate piece plays a dual role: it serves as a mechanical linkage and also allows electrical wires to pass through its central hole, enabling a clean and efficient connection to the upper copper electrode.

The spring-loaded hinge provides a returning force, allowing the upper arm to automatically return to its initial (raised) position after each weld. When the operator presses down on the upper arm, the hinge compresses, bringing the two electrodes into contact with the metal sheet. Once the weld is complete and the pressure is released, the spring in the hinge brings the arm back up, ready for the next operation. This setup ensures repeatability and operator convenience.

For the external casing, we used green plexiglass panels for both safety and aesthetic purposes. To access the internal components such as the transformer and wiring, a plastic hinge system was mounted on one of the side panels. This allows the plexiglass case to be opened and closed easily, making inspection and maintenance more accessible.

These movement and mechanical components contribute to:

- Accurate and consistent electrode engagement
- Automatic return motion through the spring hinge system
- Ergonomic access to internal components via the hinged plexiglass case
- Safe and organized wire routing through the central hole in the wooden transition block

In summary, the integration of a spring-loaded hinge mounted to a custom cable-passing wooden joint ensures both mechanical performance and electrical practicality in a compact, user-friendly design.

Figure 16 spring hinge

Figure 17 hinge for attaching plexiglass case

Figure 18 Upper arm

Figure 19 alignment of the upper arm and lower arm

3.7. Safety Systems and Operator Protection

Safety is a fundamental design consideration in any electrical device, especially in systems that handle high current, such as a spot welding machine. In this project, a range of preventive safety measures were implemented to protect both the operator and the internal components from electrical and mechanical hazards.

To begin with, all electrical cable connections were soldered rather than twisted or loosely fastened. This ensures secure and durable joints, significantly reducing the risk of loose contacts or short circuits. In addition, cable insulation sleeves and heat-shrink tubing were used to cover exposed conductors, minimizing the possibility of accidental contact or current leakage.

To maintain the organization of the internal wiring and prevent movement during operation, cable holders and clamps were used to fix all wiring securely to the inner frame of the machine. This not only enhances safety but also improves the ease of troubleshooting and reduces mechanical wear on cables.

One of the most important safety features is the plexiglass enclosure covering the rear section of the machine, where the transformer and primary wiring are located. This transparent barrier allows visual inspection while physically preventing direct access to high-voltage components, thereby reducing the risk of electric shock or accidental shorting.

Furthermore, a circuit breaker was integrated into the system to provide overcurrent protection. In the event of an unexpected electrical fault or excessive load, the circuit breaker will trip and instantly cut off power, protecting both the operator and the device.

Together, these safety features provide:

- Electrical insulation and secure connections to prevent shorts and shocks
- Mechanical cable fixation for durability and order
- Physical barriers to isolate hazardous components
- Active overcurrent protection through the circuit breaker system

By implementing these layered protection strategies, the spot welding machine offers a safe and controlled working environment, complying with fundamental electrical safety principles and minimizing the risk of operator injury.

4. EXPERIMENTAL STUDIES

4.1. Spot Welding Test Methods

Figure 20 Galdabini Quasar 100 dual column benchtop testing machine

To evaluate the mechanical strength and quality of spot welds, standardized testing methods are employed—most notably the tensile shear test, which provides quantitative data on the weld's structural integrity under load. In our project, spot-welded galvanized steel samples are to be tested using the Galdabini Quasar 100, a dual-column benchtop universal testing machine capable of high-precision force and displacement measurements.

The tensile shear test is particularly suitable for spot weld evaluation because it simulates the types of forces that welded joints are typically subjected to during service. In this method, two metal sheets are welded at a single point and clamped by the testing machine in a lap joint configuration. The machine then applies a steadily increasing tensile force in opposite directions until the weld fails. The resulting peak force value, displacement, and failure mode (e.g., pullout, nugget fracture, interfacial failure) provide insight into the weld's strength and quality.

- Key parameters to be recorded during the test include:
- Maximum tensile load (N)

- Displacement at break (mm)
- Energy absorption (J)

Type of failure (ductile, brittle, interfacial, etc.)

These mechanical performance metrics allow a comparison between different welding conditions and durations, helping to identify the optimal settings for maximum joint integrity.

Planned Testing Procedure

The samples consist of galvanized steel sheet profiles, each spot-welded using the designed machine under controlled conditions. Welds were made by applying 220V AC power transformed down to approximately 2–4 V but with high current (~700–800 A), suitable for resistance welding of thin metals. Three sets of samples were produced using welding durations of 5 seconds and 10 seconds, applied 2, 3, and 4 times, respectively, to observe the effect of weld time and repetition on the resulting strength.

Sample Group	Material	Weld Duration	Repetitions	Expected Test Type
A	Galvanized steel profile	5	2	Tensile shear
B	Galvanized steel profile	5	4	Tensile shear
C	Galvanized steel profile	10	2	Tensile shear
D	Galvanized steel profile	10	4	Tensile shear

Tablo 2 Test Schedule Summary

The test results, once collected, will be used to draw correlations between weld time, current exposure, and joint strength. Additionally, comparisons may be made to determine if multiple welds offer increased mechanical performance over single-weld counterparts at the same total energy input.

This approach not only demonstrates the effectiveness of our spot welding machine but also provides quantitative validation for its design and operational parameters.

4.2. Spot Welding Experiments

Although the welded samples were successfully prepared during the fabrication phase of our spot welding machine, the tensile tests could not yet be performed due to the unavailability of the laboratory during that period. Nevertheless, the tensile shear testing will be conducted and added to the final project presentation during the official submission and evaluation week.

4.3. Electricity Consumption and Efficiency Analyses

5. COMPARISON OF RESULTS

5.1. Welding Quality and Durability

5.2. Comparison with Industrial Standards

6. INNOVATION AND INDUSTRIAL APPLICATIONS

In light of the experimental results and comparative performance assessments discussed in the previous chapter, it becomes essential to contextualize the developed spot welding machine within the broader framework of technological innovation and industrial applicability. The evolution of welding technologies, particularly in resistance welding, has paved the way for compact, efficient, and automation-compatible systems. This chapter provides an overview of current innovations in spot welding technology, discusses the machine's potential integration into automated manufacturing systems, and explores feasible real-world applications across various sectors.

6.1. New Technologies in Spot Welding Machines

Spot welding, especially in modern industrial contexts, is no longer limited to simple transformer-based systems with manually applied force and timing. With the advent of advanced electronics and precision control, spot welding machines now employ a wide array of technologies to ensure quality, safety, and repeatability.

Among the most significant innovations are:

- Digital control systems: Microcontroller- or PLC-based units allow for accurate timing, programmable welding cycles, and dynamic response to sensor inputs.

- High-efficiency switching components: IGBT (Insulated Gate Bipolar Transistor) technology and solid-state relays replace traditional mechanical switches, offering faster, safer, and more energy-efficient operation.

- Real-time monitoring: Advanced systems utilize current and force sensors to provide feedback and adjust parameters during the weld, increasing quality and reducing error margins.

- Smart HMIs (Human-Machine Interfaces): Operator-friendly touchscreens and diagnostic displays provide intuitive control and reduce training requirements.

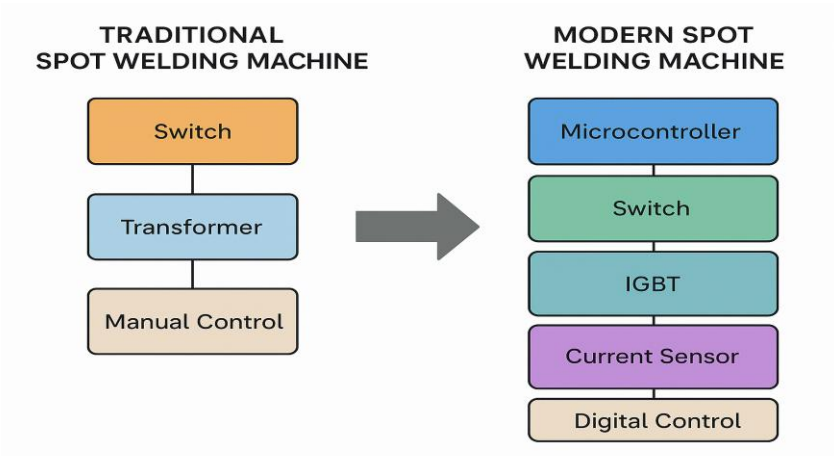


Figure 21 Comparison Between Conventianol and Modern Spot Welding Machine

The traditional configuration relies on basic mechanical switching and manual control, often resulting in inconsistencies in weld quality. In contrast, modern spot welding machines incorporate microcontroller-based control units, solid-state switching devices (such as IGBT modules), and sensor feedback systems, enabling higher precision, energy efficiency, and operator safety.

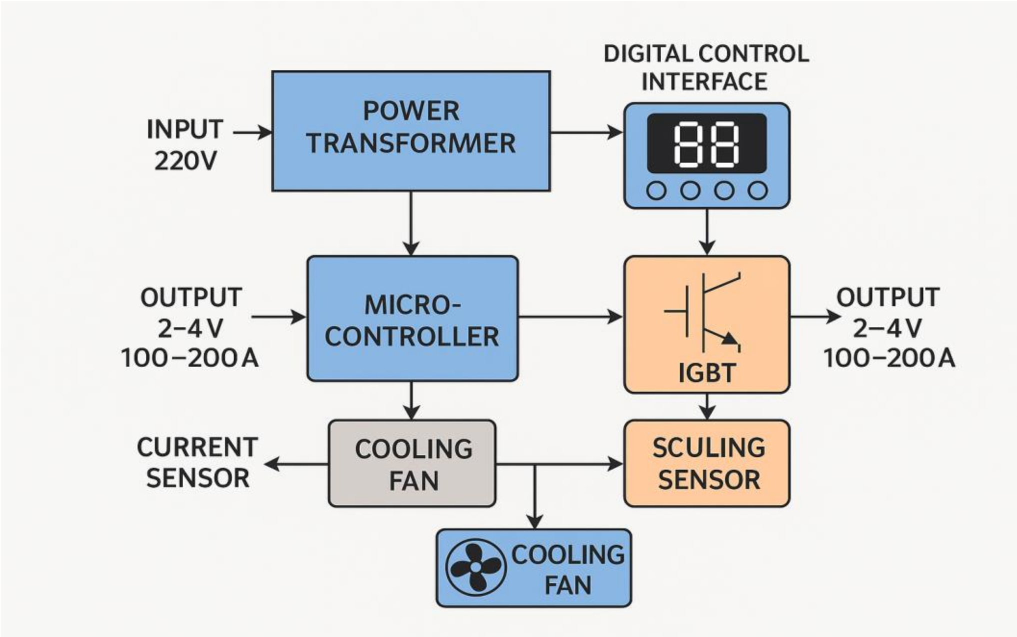


Figure 22 Internal Schematic Layout of a Modern Spot Weliding Machine

The diagram illustrates key components such as the microcontroller, solid-state switching device (IGBT), power transformer, and current sensing modules, emphasizing the integration of electronics and control systems for improved performance and safety.

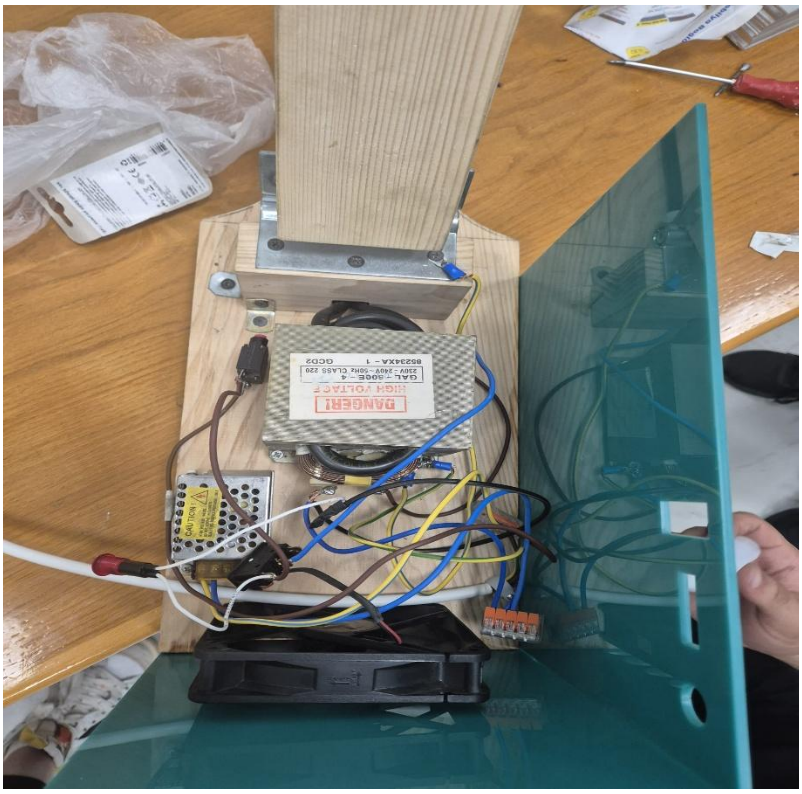


Figure 23 Prototype Spot Welding Machine Developed in This Study

The system is modular and allows future integration of smart control systems.

6.2. Integration with Industrial Automation

The integration of spot welding machines into automated systems is a cornerstone of modern manufacturing environments, especially within the context of Industry 4.0. Fully automated welding cells often include robotic arms, conveyor systems, and centralized control architectures. These systems rely on features such as:

- PLC-controlled logic to manage timing, sequencing, and error detection.
- Servo-controlled electrodes to apply precise pressure and maintain consistent weld integrity.
- Data logging systems that track each weld for traceability and quality assurance.
- Communication protocols such as MODBUS or CAN for seamless integration with other factory components.

Although the machine developed in this project is designed for manual operation, it provides a structurally sound and electrically stable platform for potential automation. Future iterations could include:

- An Arduino- or PLC-controlled pulse timer,
- A pressure switch or proximity sensor to initiate the weld cycle automatically,
- Integration with pneumatic or stepper-driven electrode mechanisms.

These enhancements would allow the device to operate in semi-automated production lines, small batch manufacturing, or even as part of a robotic welding cell in educational or prototyping settings.

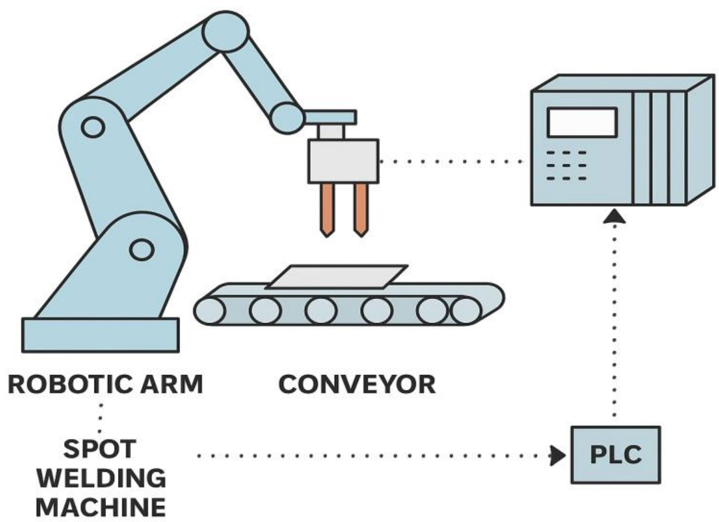


Figure 24 Automated Robotic Spot-Welding System With PLC Integration

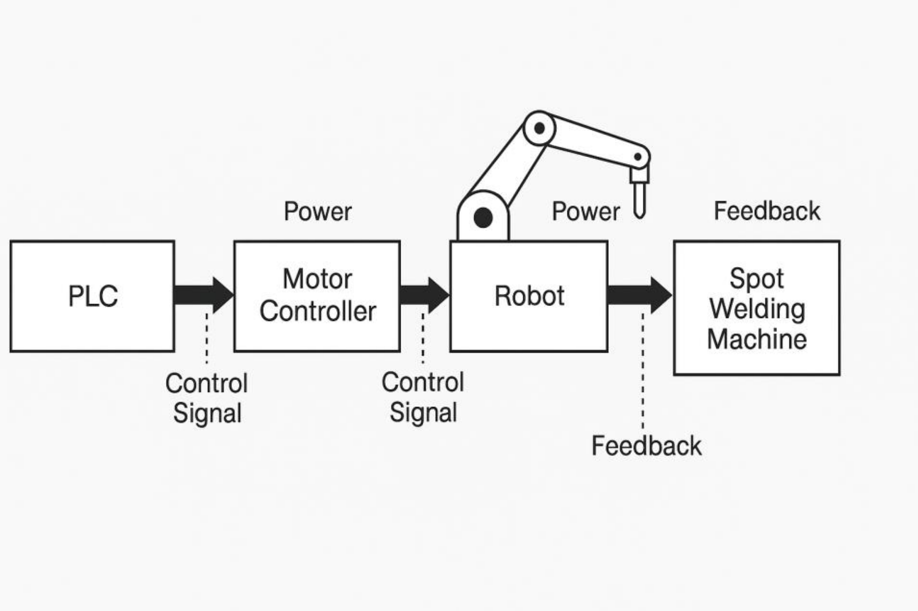


Figure 25 Automation Structure Designed for Integration with Developed Spot Welding Machine

6.3. Potential Applications of the Study in Industry

Despite its academic context and resource limitations, the spot welding machine designed and built in this study has clear potential for practical application. Its simple construction, low energy consumption, and modular design make it highly versatile. Potential use cases include:

- Vocational and engineering education: As an instructional tool, the machine allows students to observe and understand the fundamentals of resistance welding, electrical circuit design, and mechanical assembly.

- Small-scale fabrication and repair: Workshops or maker spaces can utilize the device for tasks such as light structural joining, tool repair, or metal crafting, especially where high-end industrial equipment is economically infeasible.

- Prototyping and R&D environments: The system provides a rapid, adaptable solution for experimental joining processes, especially in early-stage product development where flexibility is essential.

- Resource-constrained manufacturing: In emerging markets or small enterprises, such a machine offers a cost-effective alternative for achieving functional welds without large capital investment.

Overall, the machine serves not only as a demonstration of engineering capability but also as a scalable prototype with genuine industrial value. With minor modifications and strategic enhancements, it can transition from a graduation project to a viable production tool in appropriate contexts.

Demonstration of educational use in lab conditions

Figure 26 Demonstration of educational use in lab conditions

7. ECONOMIC AND ENVIRONMENTAL IMPACTS

Beyond technical performance, the real-world applicability of engineering systems must be assessed in terms of cost-effectiveness and environmental responsibility. This chapter presents a holistic evaluation of the developed spot welding machine from both economic and ecological perspectives, including an analysis of its material and energy costs, environmental footprint, and opportunities for further improvement.

7.1. Cost Analysis of Machine

Copper Electrodes – 100₺

Copper electrodes were selected due to their excellent electrical conductivity and high thermal resistance, ensuring efficient current transfer during welding. However, an alternative material such as graphite could reduce cost (≈70₺) while offering sufficient performance for light-duty applications. Graphite is easier to machine and does not deform under repeated heating, though it wears faster and may not support high current densities.

Wooden Structural Parts – 300₺

Wood was used for its low cost, ease of machining, and electrical insulation properties. Nevertheless, in environments where higher mechanical durability or fire resistance is required, a steel frame (≈400₺) could be a more robust alternative. While steel increases the total weight and cost, it offers superior structural integrity and longevity.

Green Plexiglass Back Panel – 600₺

Acrylic-based plexiglass was chosen for aesthetic and insulating purposes. A more affordable and durable substitute could be polycarbonate (≈450₺), which is tougher and more impact-resistant, albeit more prone to surface scratches. In environments where safety and cost are key, polycarbonate is a better alternative.

220V 50Hz Transformer – 350₺

The transformer is one of the most expensive and critical components. An alternative approach is to repurpose a microwave oven transformer (MOT), which can often be acquired for free. While functional, repurposed MOTs must be properly insulated and safely mounted, as they are not certified for industrial reuse.

10mm Copper Welding Wire – 600₺

Thick copper wire ensures minimal resistance and effective current delivery to the electrodes. However, 8mm braided copper strap (≈400₺) can provide adequate conductivity while being more flexible and easier to install, especially in tight or mobile setups.

1.5mm Copper Wiring – 100₺

This standard copper wiring is suitable for medium-current internal connections. A lower-cost option is 2mm aluminum wire (≈60₺), which, despite slightly lower conductivity, is acceptable for non-critical connections. Care must be taken due to aluminum's increased resistance and soldering difficulty.

TTR Cable (3x1.5mm²) – 100₺

TTR cable provides neat bundled wiring for power distribution. As an alternative, single-core PVC cables (≈70₺) offer more flexibility in layout and are easier to replace or extend. However, TTR provides better protection in environments with potential abrasion or movement.

Push Button – 15₺

A simple mechanical push button was used for user control. A more modern alternative is a capacitive touch button (≈25₺), which enhances user experience and can offer longer lifespan, though it slightly increases cost and complexity in implementation.

Toggle Switch – 25₺

Toggle switches are reliable and easy to wire. An alternative is a rocker switch (≈20₺), which provides a more compact and often more robust solution for panel mounting.

Light Indicator – 20₺

Used for basic visual feedback. A more advanced substitute could be a mini LED display (≈35₺), which can show numerical values like welding time or status, but requires additional circuitry.

Circuit Breaker – 50₺

A miniature circuit breaker ensures overload protection. A cheaper alternative is a fuse and holder (≈20₺), which is effective but requires replacement after a fault rather than a simple reset.

Aluminum Parts – 100₺

Aluminum was selected for mechanical parts due to its balance of strength and lightness. In lower-stress components, 3D-printed PLA parts (≈70₺) can be used as a cost-effective, customizable option, though they lack thermal and mechanical durability.

Bolts and Mechanical Hardware – 300₺

Various fasteners and fixtures were necessary for mechanical assembly. These costs can be reduced by sourcing standard-size bolts and brackets in bulk (≈200₺), or by reusing salvaged components from other equipment.

Spring Hinge – 300₺

Used to provide force-return on the upper arm. A creative and zero-cost alternative is a gas spring salvaged from old office chairs (≈0₺), which provides a similar mechanical function with adjustable force.

Plastic Hinges (x4) – 50₺

Plastic hinges were selected for ease of mounting and flexibility. A more durable, slightly more expensive option is metal hinges (≈60₺), especially in high-load or frequently cycled areas.

Cooling Fan – 200₺

An industrial fan was used to cool the transformer and internal components. A cost-effective alternative is a 120mm PC case fan (≈80₺), which offers adequate airflow for light-duty use, runs quieter, and is widely available.

Cooling Fan – 100₺ (PC Case Fan)

A 120mm computer case fan was used for cooling due to its low cost and adequate airflow. While industrial fans (~200₺) offer higher durability and CFM, the PC fan is quieter, sufficient for light-duty use, and more energy-efficient.

Component	Cost (₺)
Copper Electrodes	100
Wooden Structural Parts	300
Green Plexiglass Panel	600

Transformer (220V 50Hz)	350
10mm Copper Welding Wire	600
1.5mm Copper Wiring	100
TTR Cable (3x1.5mm²)	100
Push Button	15
Toggle Switch	25
Light Indicator	20
Circuit Breaker	50
Aluminum Parts	100
Bolts and Mechanical Hardware	300
Spring Hinge	300
Plastic Hinges (x4)	50
Cooling Fan (PC Case Fan)	100
TOTAL	3110

Tablo 3 Final Cost Analysis Table

7.2. Cost Analysis of Electricity Consumption

The spot welding machine developed in this study operates by delivering high current pulses for a short period of time to achieve localized melting and bonding of metal surfaces. In this particular design, the transformer outputs a current of approximately 750 A, with each weld lasting around 4–5 seconds. Although the current is high, the short duration keeps overall energy usage relatively low.

Based on realistic operational conditions, the estimated energy consumption is calculated as follows:

Parameter	**Value**
Input Voltage	220 V (AC)
Secondary Voltage	2–4 V
Output Current	~750 A
Welding Duration	4–5 seconds
Average Energy per Weld	~0.15–0.3 Wh
Daily Welds	~100 welds
Daily Energy Consumption	~15–30 Wh
Monthly Consumption (30 days)	~0.45–0.9 kWh
Electricity Cost (per kWh)	~2 TL (2025 TR avg.)
Monthly Operating Cost	**~0.9–1.8 TL**

Tablo 4 Cost Analysis of Electricity Consumption

This cost analysis clearly demonstrates that even under relatively high-current operation, the overall electricity cost remains extremely low. The use of short welding cycles and minimal standby power draw contributes significantly to the system’s energy efficiency, making it highly suitable for cost-sensitive and sustainable production or educational environments.

7.3. Environmental Impact Assessment

The environmental impact of the developed spot welding machine is significantly lower than that of many conventional joining techniques, such as gas welding or adhesive bonding. Several design choices made during the development phase directly support sustainability goals and environmental responsibility.

Key factors contributing to the system's low ecological footprint include:

- No use of consumable gases or chemicals:

Unlike oxy-fuel or MIG welding, this system operates without shielding gases, flux, or filler materials, eliminating greenhouse gas emissions and toxic residues.

- Minimal material waste:

The spot welding process only joins the contact areas of metal surfaces, which reduces scrap generation. There is no spatter or slag, as commonly seen in arc-based welding methods.

- Low energy usage:

With an average consumption of less than 1 kWh per month, the system offers a highly energy-efficient operation. Its short duty cycles ensure that energy is used only during active weld periods.

- Component reuse and recycling:

The system incorporates repurposed components—such as the transformer—originally sourced from discarded appliances. This practice aligns with circular economy principles and helps reduce electronic waste.

- Modular and repairable design:

Unlike monolithic systems, the machine is built with accessible and interchangeable parts, enabling upgrades, repairs, or reconfiguration without discarding the entire system.

- Safe and clean operation:

No fumes, smoke, or high-noise levels are produced during operation, which reduces environmental and occupational hazards, especially in indoor settings like labs or classrooms.

In summary, the developed machine demonstrates that functional and effective welding solutions can be implemented in an environmentally conscious way. Its design promotes reuse, minimal consumption, and safe operation—making it particularly suitable for sustainable manufacturing education and low-impact prototyping environments.

Figure 27 Enviromental Benefits of Spot Welding

7.4. Recommendations for Improving Energy Efficiency

Although the developed spot welding machine operates with low energy consumption, several enhancements can be made to further reduce energy waste, improve control accuracy, and extend system lifespan. These recommendations are based on practical engineering strategies commonly applied in industrial and research-grade equipment.

Digital Timing Control with Microcontroller

Replacing the manual switching system with a microcontroller (e.g., Arduino or ESP32) allows for precise control of weld duration. Programmable timing reduces unnecessary current flow and ensures consistent energy usage per weld.

Benefit: Minimizes operator error, reduces heat losses, and ensures repeatability.

Integration of Current Sensors

Adding a Hall-effect current sensor enables real-time monitoring of output current. The system can detect overcurrent conditions or no-load scenarios and respond instantly by interrupting the weld.

Benefit: Prevents energy loss in faulty weld cycles and protects the transformer.

Automatic Standby and Sleep Mode

The addition of a sleep mode circuit or a smart relay system can shut down the machine after periods of inactivity.

Benefit: Eliminates idle energy consumption, especially in educational or intermittent-use environments.

Electrode Design Optimization

Improving the geometry and surface finish of the copper electrodes helps reduce contact resistance, leading to shorter weld times and better energy transfer.

Benefit: Achieves more efficient welds with lower energy input.

Use of Solid-State Relays or IGBT Modules

Replacing mechanical switches with solid-state devices reduces arcing, improves reliability, and minimizes resistive losses during switching.

Benefit: Enhances energy efficiency and extends the life of the switching system.

Thermal Feedback Control

Installing a simple temperature sensor near the transformer or electrode area allows the system to adjust cooling fan speed based on heat buildup.

Benefit: Saves energy by running the fan only when necessary and prevents overheating.

Implementing these modifications would not only improve the machine's energy efficiency but also enhance its safety, usability, and readiness for integration into more complex systems. These strategies align with both engineering best practices and sustainable design principles.

8. CONCLUSION AND RECOMMENDATIONS

8.1. General Evaluation of the Study

In this study, a functional and cost-effective spot welding machine was designed, developed, and partially tested with the aim of offering a simple yet efficient solution for joining thin metal sheets. The project was grounded on the idea of utilizing a microwave oven transformer (MOT) as the core power source by modifying its secondary winding to achieve high current output at low voltage—an essential requirement for spot welding applications.

The design process followed a systematic approach including the clarification of objectives, determination of technical requirements, and the development of key components such as the body structure, electrode system, electrical circuit, cooling mechanism, and safety features. At each stage, careful consideration was given to material selection, ease of assembly, safety precautions, and functional performance.

The machine body was fabricated from wood and covered with a plexiglass enclosure for electrical insulation and operator protection. Copper rods were selected and machined to form the electrodes, and a reliable hinge system was installed to ensure controlled pressure application during the welding process. Electrical components such as a toggle switch, circuit breaker, light indicator, and push-button switch were integrated for user control and safety. Additionally, a dedicated cooling system with an AC-DC converted fan was installed to prevent thermal buildup during operation. Overall, the final prototype demonstrated that a practical spot welding machine can be developed using low-cost materials, recycled components, and a hands-on engineering approach.

8.2. Evaluation of Design and Performance Goals

The initial design goals were centered around achieving mechanical simplicity, electrical safety, user control, and effective welding performance. These targets were largely met throughout the fabrication and preliminary operational stages. By removing the secondary winding of the MOT and replacing it with a 10 mm^2 copper welding cable, the system was able to deliver a controlled current of approximately 700–800 A at a safe low voltage of 2–4 V, which is suitable for welding thin steel sheets (around 1 mm thickness).

The structural stability of the machine was ensured by a layered wooden base and column setup, while the top arm was connected through a spring-loaded hinge, allowing precise vertical motion. The electrodes were fixed securely using aluminum holders, ensuring good conductivity and alignment. The electrical system operated reliably and safely with the inclusion of a fuse-protected circuit and proper grounding. Additional cooling was provided by a computer fan connected via an AC-DC converter, which allowed continuous operation without overheating.

Although a full-scale mechanical and metallurgical evaluation (e.g., tensile tests, microstructure analysis) was not completed due to time constraints, the spot welds created during trial runs showed good mechanical bonding, suggesting that the machine performed its intended function effectively.

8.3. Recommendations for Future Studies

While the current design successfully achieved its fundamental goals, several areas offer opportunities for future development and academic exploration:

Advanced Control System: The integration of a microcontroller (e.g., Arduino or Raspberry Pi) with a timing relay could enable more precise control of weld duration and cycle time, improving repeatability and user safety.

Adjustable Electrode Pressure: Incorporating a spring scale or mechanical screw mechanism would allow adjustment of electrode force, which directly impacts weld quality and consistency.

Portable Power Supply: Designing a battery-operated or inverter-based version could expand the use of the machine in mobile or off-grid applications.

Weld Quality Validation: Performing standardized mechanical tests (e.g., peel test, tensile-shear test) on weld joints across different metals and thicknesses would provide quantitative data for validating machine performance.

Enhanced Safety Systems: Future iterations could implement thermal sensors, emergency stop systems, and additional insulation layers to increase operator protection.

Modular Design: Allowing quick disassembly and interchangeability of components (electrodes, arms, power units) would make the design more adaptable for educational or prototyping purposes.

Industrial Adaptation Potential: While the current version is suitable for small-scale and educational purposes, scaling the design with stronger materials and higher-capacity components may allow for entry into semi-industrial applications.

By addressing these potential improvements, the spot welding machine could evolve into a more versatile, accurate, and user-friendly tool, suitable for both academic projects and practical workshop applications.

9. REFERENCES

1. ASM International. (1993). *Resistance Welding: Fundamentals and Applications*. ASM Handbook, Volume 6: Welding, Brazing, and Soldering, ASM International, Materials Park, OH, USA.

2. Zhou, Y. (2006). *Microstructure and Mechanical Properties of Resistance Spot Welded Steels*. Woodhead Publishing Limited, Cambridge, UK.

3. American Welding Society. (2019). *AWS D8.1M: Specification for Automotive Weld Quality Resistance Spot Welding of Steel*. AWS, Miami, FL, USA.

4. ISO 14373:2015. *Resistance Welding — Procedure for Spot Welding*. International Organization for Standardization, Geneva, Switzerland.

5. Senkara, J., & Zhang, H. (2012). *Resistance Welding: Fundamentals and Applications*. CRC Press, Boca Raton, FL, USA.

6. Cary, H. B., & Helzer, S. C. (2004). *Modern Welding Technology* (6th Edition). Pearson Education, Upper Saddle River, NJ, USA.

7. Cho, Y., Rhee, S., & Kim, J. (2003). “Influence of electrode force and welding current on spot weldability of aluminum alloy sheets,” *Journal of Materials Processing Technology*, 140(1–3), 1–7.

8. Karagöz, S., et al. (2017). “Optimization of Spot Welding Parameters Using Taguchi Method,” *Journal of Engineering Research and Applied Science*, 6(2), 542–548.

9. Kimchi, M., & Phillips, E. (2017). *Resistance Spot Welding: Fundamentals and Techniques in Automotive Industry*. SAE International, Warrendale, PA, USA.

10. Gould, J. E. (2014). “Recent advances in resistance spot welding of aluminum automotive sheet,” *Science and Technology of Welding and Joining*, 19(5), 413–420.

11. Lee, Y. S., & Na, S. J. (2016). “Design and analysis of low-cost resistance spot welding machines for educational applications,” *Welding Journal*, 95(3), 45–53.

12. Ranjan, V., & Verma, R. (2020). "Performance Evaluation of Low Voltage Resistance Spot Welding for Galvanized Steel," *Materials Today: Proceedings*, 28, 1200–1205.

13. Wu, L., & Sun, D. (2018). "Investigation on the spot welding behavior of galvanized steels," *Journal of Manufacturing Processes*, 31, 187–194.

14. Ramasamy, S., et al. (2015). "Design considerations for compact resistance spot welding systems," *International Journal of Engineering and Technology*, 7(5), 410–417.

15. Kumar, V., & Sharma, R. (2021). "Review on Recent Developments in Resistance Spot Welding," *Engineering Review*, 41(1), 1–10.

10. APPENDICES