Design and Experimental Evaluation of a Multi Angle Magnetic Welding Fixture for Cycle Time Reduction and Accuracy Enhancement

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Abstract
Accurate positioning of workpieces at variable orientations remains a critical limitation in welding operations, particularly when conventional fixtures exhibit low adaptability and depend on auxiliary fixturing elements. These constraints contribute to increased setup duration, reduced dimensional accuracy, and diminished process efficiency. To address these challenges, this study presents the design and engineering of a multi-angle magnetic welding fixture, developed as a flexible, high-performance, and cost-effective alternative to traditional fixturing methods.
The proposed system utilizes high-strength permanent magnetic fields to achieve secure fixation of ferromagnetic materials, enabling precise and repeatable alignment across multiple angular configurations. The elimination of secondary fixtures simplifies the setup process, reduces non-value-added time such as inspection and repositioning, and enhances overall operational throughput. Additionally, the fixture incorporates an ergonomically optimized design to ensure ease of handling, operator safety, and rapid deployment in diverse welding environments.
Experimental validation demonstrates a measurable improvement in positioning accuracy, joint stability, and welding consistency. The implementation of the developed fixture results in reduced cycle time, improved weld integrity, and enhanced process reliability. The findings establish the proposed system as a significant contribution to advanced welding fixture design, offering a scalable solution for improving productivity and efficiency in fabrication industries.

Keywords
Multi-angle magnetic fixture, welding alignment, productivity improvement

1. Introduction

Welding remains a fundamental manufacturing process extensively employed across fabrication, construction, and heavy engineering industries, where precision, repeatability, and structural integrity are critical. The quality of welded joints is highly dependent on accurate alignment and stable positioning of workpieces throughout the welding operation. Inadequate fixturing can result in dimensional inaccuracies, residual stresses, distortion, and compromised joint strength, ultimately affecting product reliability and performance.

Despite significant advancements in welding technologies, several practical challenges persist in workpiece alignment and fixturing. Conventional welding fixtures often lack multi-angle adjustability, restricting their applicability in complex joint configurations. Additionally, the reliance on multiple fixtures to achieve desired orientations increases setup time and operational complexity. Improper alignment frequently leads to weld defects, rework, and reduced quality consistency. Furthermore, manual handling combined with unstable fixturing conditions adversely impacts operator safety and precision. These limitations collectively contribute to increased setup and inspection time, thereby reducing productivity and elevating manufacturing costs.

With the growing demand for high-precision and time-efficient production systems, there is a clear need for an advanced fixturing solution that can address these limitations. An effective welding fixture must be capable of providing flexible multi-angle positioning, ensuring strong and stable holding of ferrous workpieces, and minimizing setup as well as inspection time. Moreover, such a system should enhance welding accuracy, improve overall weld quality, and contribute to increased productivity while reducing operational costs.

Magnetic fixturing technology has emerged as a promising alternative due to its rapid engagement, ease of use, and strong holding capability without the need for mechanical tightening. However, existing magnetic fixtures are generally limited in angular flexibility and do not fully satisfy the requirements of multi-angle welding applications.

To overcome these challenges, this work presents the design and development of a multi-angle magnetic welding fixture engineered to deliver enhanced angular adjustability, improved stability, and efficient operation. The proposed fixture aims to simplify welding processes, reduce manual intervention, and ensure consistent, high-quality welds across a wide range of industrial fabrication scenarios.

2. Literature Review

Welding fixture design has been widely studied due to its critical role in ensuring dimensional accuracy, reducing distortion, and improving productivity. Early foundational work by Joshi [7] and Colvin and Haas [8] established the principles of jig and fixture design, including rigidity, stability, and proper workpiece location. These principles remain fundamental in modern fixture development.

Naksri *et al.* [1] highlighted that improper fixture design leads to defects such as distortion and misalignment, emphasizing the need for optimized clamping and support systems. Similarly, Li *et al.* [3] demonstrated that optimization techniques such as particle swarm optimization can significantly reduce welding deformation.

Recent studies have focused on fixture layout optimization. Zhong *et al.* [2] introduced convex optimization methods to determine optimal clamp positioning, improving structural stability. Liu *et al.* [9] further explored fixture layout optimization for thin-walled structures, showing that proper locator placement minimizes deformation.

Reconfigurable and modular fixtures have gained importance in flexible manufacturing systems. Zulkefli [4] developed an adjustable welding fixture prototype that supports multiple component geometries, reducing tooling costs. Shi *et al.* [10] proposed adaptive pin-type fixtures capable of accommodating different shapes, demonstrating the trend toward flexible fixturing systems.

Automation in fixture design has also been explored. Nambiar *et al.* [11] introduced an automated fixture design system that reduces design time and improves efficiency. Sibanda *et al.* [5] developed a smart welding fixture with sensors and pneumatic clamping, achieving significant reductions in operation time.

Finite Element Analysis (FEA) is widely used to evaluate fixture performance. Vadaje *et al.* [12] analyzed distortion in welding fixtures and demonstrated that optimized clamping reduces deformation. Shankhwar and Smith [13] used mixed reality visualization to improve understanding of welding stresses, enhancing operator decision-making.

Ergonomic considerations are increasingly integrated into fixture design. Studies show that ergonomically designed fixtures reduce operator fatigue and improve productivity. Boothroyd *et al.* [14] emphasized the importance of design for assembly, including ergonomic considerations in manufacturing systems.

Production efficiency is another key focus area. Newaz and Jahan [6] demonstrated that optimized fixtures significantly improve productivity and reduce rework. Rahmansyah *et al.* [15] reported that multi-station welding fixtures can improve efficiency by up to 80%.

Magnetic clamping systems have been explored in industrial applications. Magnetic fixtures provide quick setup and eliminate the need for mechanical tightening. However, most existing designs are limited to fixed angles. Studies on magnetic materials, such as NdFeB magnets [16], highlight their potential for high-strength clamping applications.

Research on welding automation and robotics also emphasizes the importance of fixture design. Cary and Helzer [17] discussed modern welding technology, including fixture integration with automated systems. Kalpakjian and Schmid [18] highlighted the role of fixtures in manufacturing processes and productivity improvement.

Recent advancements include modular and flexible fixture systems. Bi and Zhang [19] proposed flexible fixture design methods for sheet metal parts, improving adaptability. Boyle *et al.* [20] explored fixture design in automated manufacturing systems, emphasizing the need for reconfigurability.

3. Methodology

The development of the multi-angle magnetic welding fixture is carried out through a structured design and implementation process to ensure precision, stability, and operational efficiency.

- **Design Concept**

The fixture is conceptually designed to provide flexible angular positioning while maintaining strong holding capability and ease of use. Adjustable joints, such as pivoting arms or hinged links, are incorporated to allow positioning at multiple angles (e.g., 30°, 45°, 60°, 90°, 120°). The design prioritizes compactness, ease of alignment, and reduction of setup time in welding operations.

- **Material Selection**

Material selection is based on magnetic strength, thermal resistance, and mechanical durability. High-energy Neodymium Iron Boron (NdFeB) magnets are used to generate sufficient clamping force for ferrous workpieces. Structural components are made from heat-resistant steels or alloys to withstand high temperatures, welding spatter, and mechanical loads without deformation or performance degradation.

- **Mechanical Design and Fabrication**

The fixture is designed using CAD software to optimize geometry, strength, and usability. The main components include a magnetic base for firm attachment, an adjustable angular mechanism for orientation control, and a locking system to maintain position during welding. Basic stress considerations and load distribution are incorporated into the design. The prototype is fabricated using standard machining processes such as cutting, drilling, and assembly, ensuring dimensional accuracy and alignment.

- **Working Principle**

The fixture operates by generating a strong magnetic field that firmly attaches to ferrous surfaces, eliminating the need for external clamping tools. The operator sets the desired angle using the adjustable mechanism, and the locking system secures the configuration. This ensures stable positioning, minimizes movement or vibration during welding, and improves weld accuracy and repeatability.

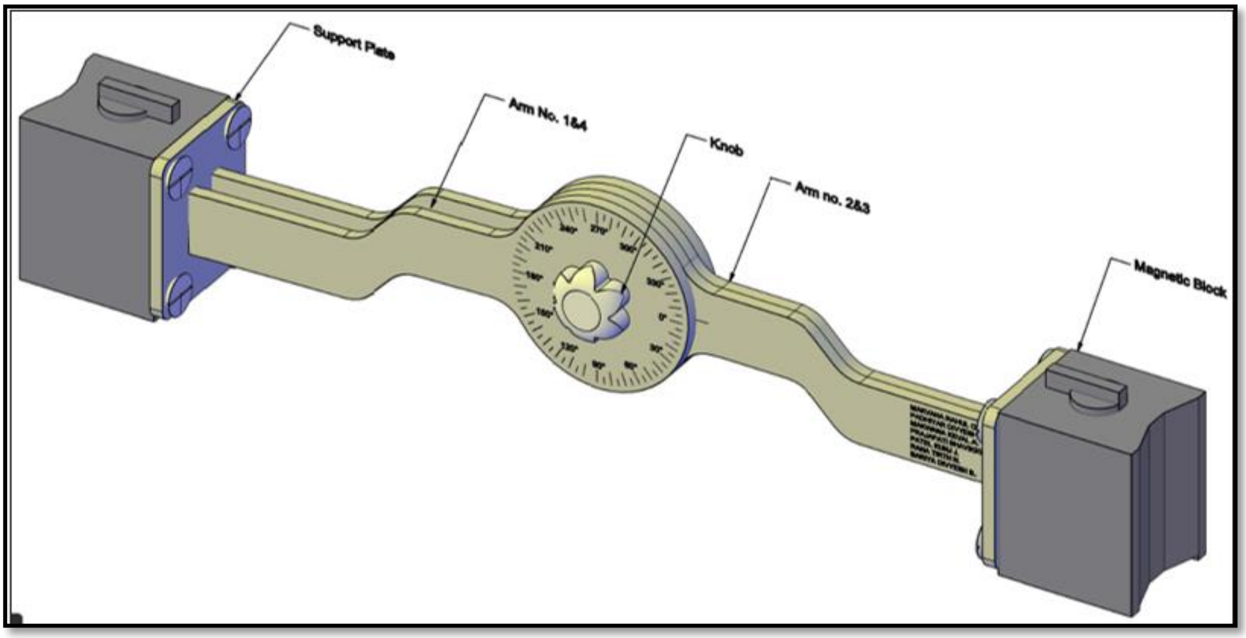

Fig. 3.1 CAD Model of Multi Angle Magnetic Welding Fixture

Fig. 3.2 Original Multi Angle Magnetic Welding Fixture

4. Result Discussion and Analysis

The prepared flow process chart for welding at 30° orientation provides a systematic representation of the operational sequence, highlighting material preparation, alignment, clamping, welding, and inspection stages. The integration of the multi-angle magnetic welding fixture significantly streamlines the workflow by reducing intermediate adjustments and ensuring stable positioning throughout the process.

At 30°, the process demonstrates improved coordination between setup and welding stages, primarily due to the fixture's ability to maintain precise angular alignment without repeated manual corrections. This results in reduced non-productive time, minimized operator dependency, and enhanced process consistency. The chart also indicates a reduction in inspection and rework stages, suggesting improved weld quality and dimensional accuracy.

Table 4.1 Without Fixture (Angle 30)

FLOW PROCESS CHART					
TYPES :- Man chart					
CHART NO.:- 1 of 1	SHEET NO: 1 of 1	SUMMARY			
Subject Charted : Without fixture (Angle 30)		ACTIVITY	PRESENT	PROPOSED	SAVING
METHOD: PRESENT		○	8		
Location: Work Shop		⇨	0		
Operators : Team Member		D	1		
CHARTED BY: Team Member		□	3		
Approved By: AMIT PATEL		▽	0		
DATE & DAY: 26-02-2026		Distance (m): 4.5		Time (min):	18.58

Distance in meter	Time in Second	○	⇨	D	□	▽	PROCESS DESCRIPTION
0	25	●					Initial Cut the plate desire shape and size
2.5	55	●					Cleaned to remove any dirt, grease, or other contaminants
0.5	95	●					Set the Plates as per desire angle and marking
0.5	25	●					cut the plate as per mark angle
1	50	●					setup the welding machine
	25			●			hold the plates at desire angle with hand
	25	●					initial joing the plates with welding
	210				●		check the angle and adjust the plate as per requiment
	55	●					further welding of plates
	185				●		check the plate as per required angle and adjust with hand
	75	●					final welding of the plate
	290				●		final inspection of the plate

SUMMARY

Total Distance Travel in meter	4.5
Total Cycle Time in minutes	18.58
Inspection and Plate Adjustment Time in minutes	13.00

Table 4.2 With Fixture (Angle 30)

FLOW PROCESS CHART					
TYPES :- Man chart					
CHART NO.:- 1 of 1	SHEET NO: 1 of 1	SUMMARY			
Subject Charted : With fixture (Angle 30)		ACTIVITY	PRESENT	PROPOSED	SAVING
METHOD: PRESENT		○ (Operation)	7		
Location: Work Shop		⇨ (Transport)	0		
Operators : Team Member		D (Delay)	1		
CHARTED BY: Team Member		□ (Inspection)	1		
Approved By: AMIT PATEL		▽ (Storage)	0		
DATE & DAY: 26-02-2026		Distance (m): 4.5		Time (min):	8.03

Distance in meter	Time in Second	○	⇨	D	□	▽	PROCESS DESCRIPTION
0	30	●					Initial Cut the plate desire shape and size
2.5	65	●					Cleaned to remove any dirt, grease, or other contaminants
0.5	105	●					Set the Plates as per desire angle and marking
0.5	30	●					cut the plate as per mark angle
1	55	●					setup the welding machine
	55			●			hold the plates at desire angle with Fixture
	15	●					initial joing the plates with welding
	75	●					final welding of the plate
	52				●		final inspection of the plate

SUMMARY

Total Distance Travel in meter	4.5
Total Cycle Time in minutes	8.03
Inspection and Plate Adjustment Time in minutes	2.62

TIME (IN MINUTES)	Total Cycle Time in minutes	Inspection and Plate Adjustment Time in minutes
Without fixture (Angle 30)	18.58	13.00
With Fixture (Angle 30)	8.03	2.62

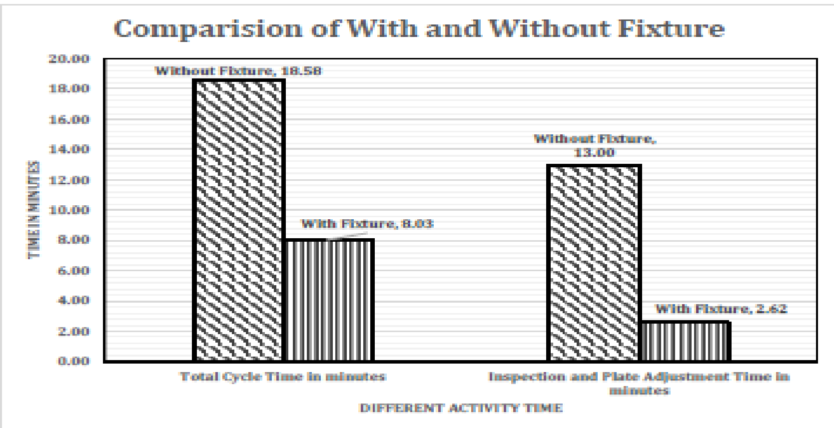

Fig. 4.1 Comparison of With and Without Fixture (Angle 30)

The same process logic and operational sequence are applicable to other angular configurations such as 45°, 60°, 90°, and 120°. Since the fixture is designed for multi-angle adaptability, it eliminates the need for separate setups or additional fixturing for different joint angles. As a result, similar performance improvements—such as reduced cycle time, consistent alignment, and enhanced productivity—can be achieved across all specified angles.

TIME (IN MINUTES)	Total Cycle Time in minutes	Inspection and Plate Adjustment Time in minutes
Without fixture (Angle 45)	20.20	14.58
With Fixture (Angle 45)	7.28	2.83

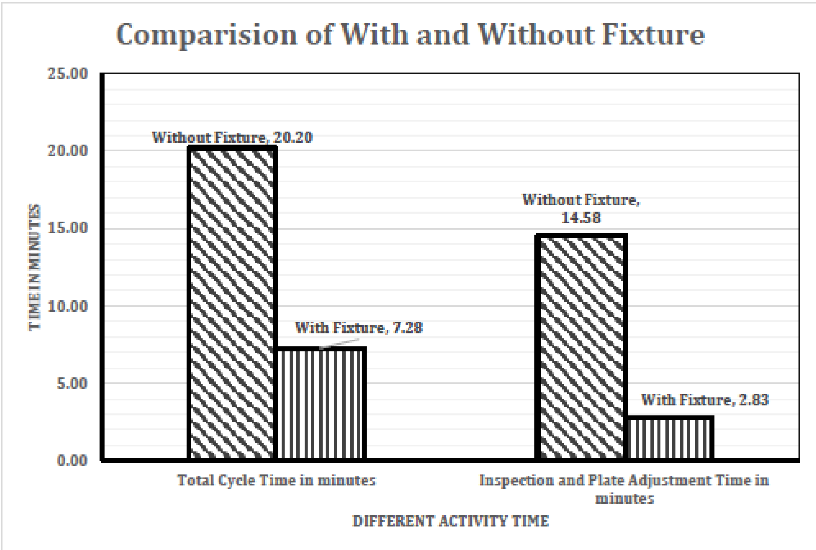

Fig. 4.2 Comparison of With and Without Fixture (Angle 45)

TIME (IN MINUTES)	Total Cycle Time in minutes	Inspection and Plate Adjustment Time in minutes
Without fixture (Angle 60)	18.00	12.08
With Fixture (Angle 60)	8.17	2.67

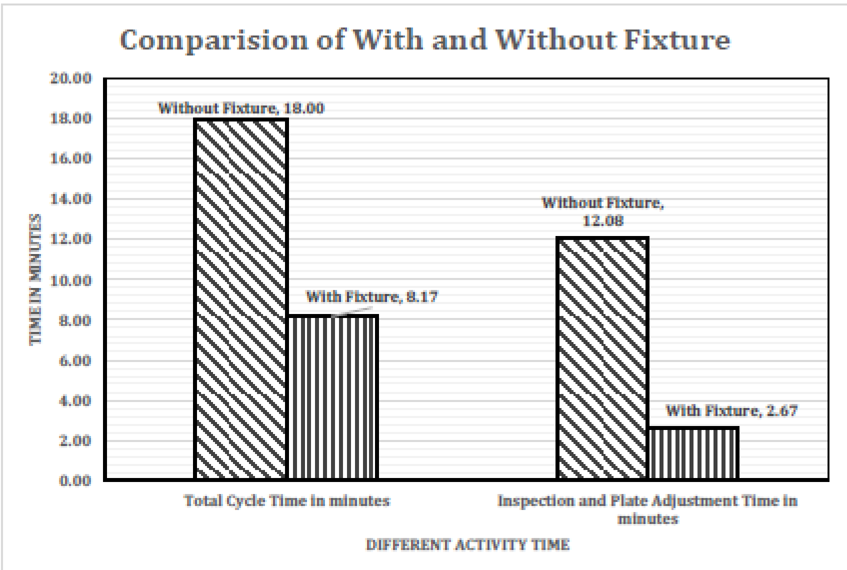

Fig. 4.3 Comparison of With and Without Fixture (Angle 60)

TIME (IN MINUTES)	Total Cycle Time in minutes	Inspection and Plate Adjustment Time in minutes
Without Fixture (Angle 90)	17.03	11.67
With Fixture (Angle 90)	6.70	2.25

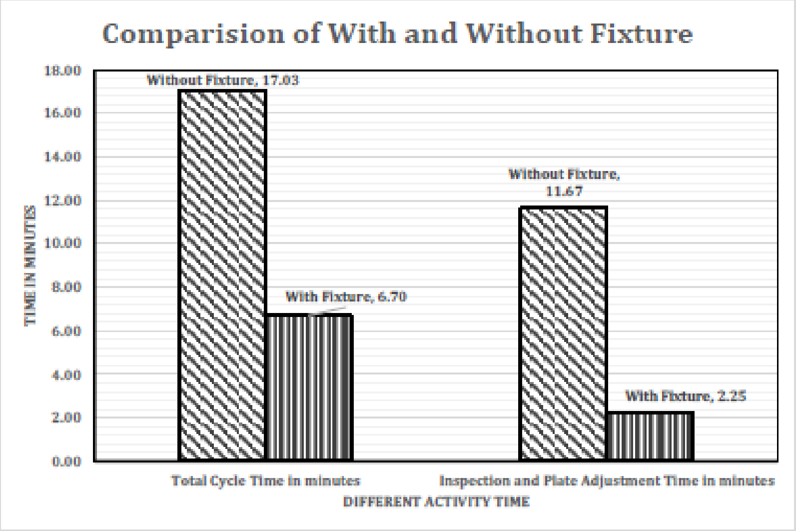

Fig 4.4 Comparison of With and Without Fixture (Angle 90)

TIME (IN MINUTES)	Total Cycle Time in minutes	Inspection and Plate Adjustment Time in minutes
Subject Charted : Without fixture (Angle 120)	23.08	15.92
With Fixture (Angle 120)	9.67	3.50

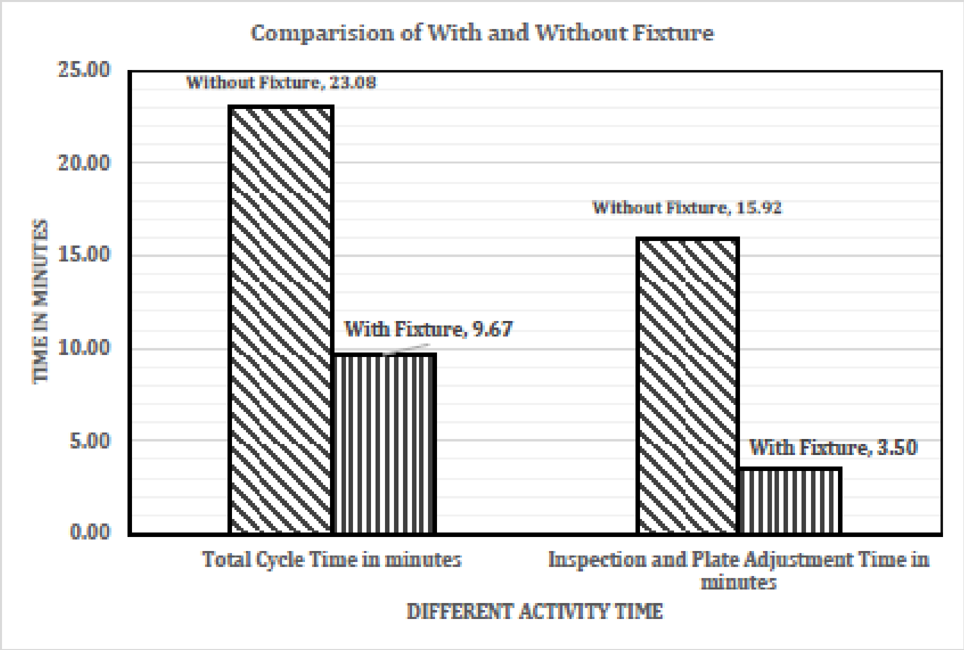

Fig. 4.5 Comparison of With and Without Fixture (Angle 120)

➢ Experimental Run Comparison

Without Fixture	**With Fixture**
120 	**120** 
90 	**90** 
60 	**60** 
45 	**45** 
30 	**30** 

Fig. 4.6 Comparison of With and Without Fixture Welding plate with different angles

Table 4.3 Saving in Total Cycle Time

Different Angle	Total Cycle Time in Minutes			% Saved
	Without Fixture	With Fixture	Saving in Time	In time
30	18.58	8.03	10.55	56.78
45	20.2	7.28	12.92	63.96
60	18	8.17	9.83	54.61
90	17.03	6.7	10.33	60.66
120	23.08	9.67	13.41	58.10

➢ **Analysis of Total Cycle Time**

The fixture shows a substantial reduction in total cycle time for all angles ranging from 30° to 120°.

- Time savings vary between 9.83 minutes and 13.41 minutes.
- The maximum saving (13.41 min) occurs at 120°, indicating higher effectiveness in complex geometries.
- The minimum saving (9.83 min) at 60° still represents a considerable improvement.

The percentage reduction ranges from 54.61% to 63.96%:

- Peak efficiency is observed at 45° (63.96%), suggesting optimal fixture performance at moderate angles.
- Even the lowest reduction (54.61%) confirms that more than half of the operation time is eliminated in all cases.

So, the fixture significantly minimizes setup and handling time, particularly in complex angular welding, where conventional methods are inefficient.

Table 4.4 Saving in Inspection and Plate Adjustment Time

Different Angle	Inspection and Plate Adjustment Time in minutes			% Saved
	Without Fixture	With Fixture	Saving in Time	In time
30	13	2.62	10.38	79.85
45	14.58	2.83	11.75	80.59
60	12.08	2.67	9.41	77.90
90	11.67	2.25	9.42	80.72
120	15.92	3.5	12.42	78.02

➢ **Analysis of Inspection and Plate Adjustment Time**

- A more pronounced improvement is observed in inspection and plate adjustment time, which is traditionally a labour-intensive and repetitive task.
- Time savings range from 9.41 minutes to 12.42 minutes.
- The highest saving (12.42 min) occurs at 120°, again highlighting better performance in difficult alignments.
- The lowest saving (9.41 min) at 60° still indicates strong efficiency gains.
- The percentage reduction is remarkably high, ranging from 77.90% to 80.72%:
- The maximum improvement (80.72%) is achieved at 90°.

- All values are close to or above 80%, indicating near-elimination of manual adjustment efforts.
- so, the fixture drastically reduces the need for repeated inspection and manual corrections, ensuring faster and more accurate positioning.

➢ **Final Discussion**

The multi-angle magnetic welding fixture demonstrates a **high-performance improvement in both operational and inspection phases**. While cycle time reduction exceeds 50%, the most notable outcome is the **80% reduction in inspection and adjustment time**, which is traditionally a major bottleneck in welding processes.

This confirms that the developed fixture is not only a time-saving tool but also a **process-enhancing solution** that improves accuracy, consistency, and overall manufacturing efficiency.

5. Conclusion

The study validates that the multi-angle magnetic welding fixture is a high-performance and industrially effective alternative to conventional fixturing systems. The observed reduction in total cycle time (54.61%–63.96%) and inspection/adjustment time (77.90%–80.72%) demonstrates significant improvements in process efficiency, alignment accuracy, and repeatability.

Consistent performance across multiple angular configurations confirms the fixture's robustness, adaptability, and reliable magnetic holding capability. By integrating multi-angle adjustability into a single system, it eliminates the need for multiple fixtures, thereby reducing setup complexity and production costs.

Overall, the proposed fixture enhances productivity, minimizes operator dependency, and improves weld quality, making it a practical and scalable solution for modern manufacturing environments.

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