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Design and Development of a Spring-Type Fixture for Manufacturing Efficiency

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ABSTRACT

The development and design of a spring-type fixture play a critical role in enhancing the precision and efficiency of manufacturing processes that require repetitive assembly or testing. This research focuses on the design, and fabrication of a spring-loaded fixture aimed at improving workpiece positioning, alignment, and clamping accuracy in various industrial applications. By integrating a spring mechanism, the fixture provides adaptive flexibility, enabling consistent pressure and secure holding, thereby minimizing operator-induced errors and increasing production throughput. The study presents a detailed analysis of the fixture's mechanical design, including the selection of materials, and dimensions while maintaining cost-effectiveness. Cutting simulations are conducted using MasterCAM software to assess toolpath accuracy and detect potential collisions, optimizing the fixture's functionality. The results demonstrate that the spring-type fixture achieves significant improvements in repeatability and precision, particularly in industries such as automotive, aerospace, and electronics. This design contributes to the advancement of fixture technology by offering a solution that enhances both operational consistency and efficiency in high-precision manufacturing environments.

Keywords: Design, Spring-type fixture, MasterCAM, High-precision manufacturing.

1. INTRODUCTION

Assembly fixtures are essential in modern production and manufacturing industries, where they serve the critical function of securely holding, aligning, and positioning components during the assembly process. By ensuring that parts are consistently and precisely oriented, assembly fixtures enhance not only the accuracy but also the repeatability of the manufacturing process, reducing human error and variability [1, 2]. This is especially vital in industries with strict quality standards, such as electronics, medical devices, automotive, and aerospace, where even minor deviations can lead to significant operational or safety issues [3, 4, 5, 6].

In addition to improving precision, assembly fixtures also contribute to production efficiency by streamlining operations, allowing for faster assembly with minimal manual intervention. This leads to reduced cycle times and increased throughput. Moreover, the use of specialized fixtures can facilitate automation, making them essential for high-volume manufacturing environments where both consistency and speed are paramount [7, 8, 9]. Through the adoption of assembly fixtures, manufacturers can achieve tighter tolerances, better quality control, and lower overall production costs, which are essential factors in maintaining competitiveness in these advanced industries.

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The project's primary objective is to improve the field of assembly fixtures by developing spring-based solutions that satisfy several critical objectives. Most importantly, these fixtures offer unparalleled accuracy and reproducibility due to the use of precision engineering principles. To minimize mistakes throughout the assembly process and fulfill strict quality requirements, accuracy is essential. This improves the final product's performance and dependability.

Efficiency is another major project focus area. The fixtures are designed to save worker needs, setup durations, and assembly procedures by combining modern automation technologies with ergonomic design elements [10, 11]. This increases worker comfort and safety, reduces the danger of injury from repetitive strain, and raises workplace satisfaction levels in addition to increasing productivity. Simulation enables the optimization of spring-based assembly fixtures by analyzing performance under various conditions, ensuring precision, durability, and efficiency before physical implementation [12].

One essential component of the suggested solutions is their durability. The fixtures are made to resist the stresses of industrial use by using strong design concepts and carefully selecting high-quality materials [13]. These fixtures provide long-term dependability and cost-effectiveness by reducing wear and tear and lengthening the maintenance intervals, ensuring minimal disruption and optimum uptime for manufacturing processes.

The length of a solder joint plays a key role in how it handles thermal stress. Longer solder joints can be more flexible but may develop weak points over time, while shorter ones are stiffer but might crack under repeated heating and cooling. By carefully designing solder joint lengths in assembly fixtures, manufacturers can distribute stress more evenly, improving the strength and lifespan of soldered parts [14]. This is especially important in industries like electronics and aerospace, where reliability and precision are critical.

An additional important factor in the project is versatility. Exceptional versatility is provided by the fixtures' adaptable component architecture and compatibility with a wide range of assembly activities and automation systems. This flexibility improves efficiency and adaptability in complex manufacturing environments by enabling manufacturers to quickly modify their assembly lines to match changing production demands [15].

Additionally, the project places a high priority on the economy without sacrificing quality. Through the optimization of production procedures and material selection, the fixtures are designed to provide outstanding performance at a cost-effective price. Because these fixtures are easily accessible, organizations of all sizes including small and medium-sized enterprises (SMEs) can make use of their sophisticated capabilities without going over their costs.

With all factors considered, the project is a thorough attempt to produce cutting-edge screw-based fixtures that best in accuracy, effectiveness, durability, adaptability, and cost-effectiveness, consequently improving assembly processes across sectors. The proposed spring-based fixtures prioritize quality by ensuring precise, repeatable assembly processes that minimize defects and consistently meet stringent industry standards [15]. The initiative hopes to significantly improve product quality, operational excellence, and production efficiency by achieving these goals.

2. MATERIAL AND METHODS

2.1 Product Design

The 3D model of the spring-loaded fixture, as shown in Figure 1, consists of multiple components, including the base plate, guide pins, and compression springs. These elements work together to provide the necessary mechanical alignment and stability during the operational cycle. The top plate is designed with mounting features to hold the test component securely while ensuring that it can be positioned accurately within the fixture.

The fixture's dimensions, depicted in Figure 2 indicated in the technical drawings, provide detailed specifications for fabrication. The overall width and height of the base and top plates are 130 mm and 210 mm, respectively. The tolerances on critical dimensions are set to ensure proper alignment and functioning of the springs. Figure 3 depicts the exploded view of the spring-loaded fixture.

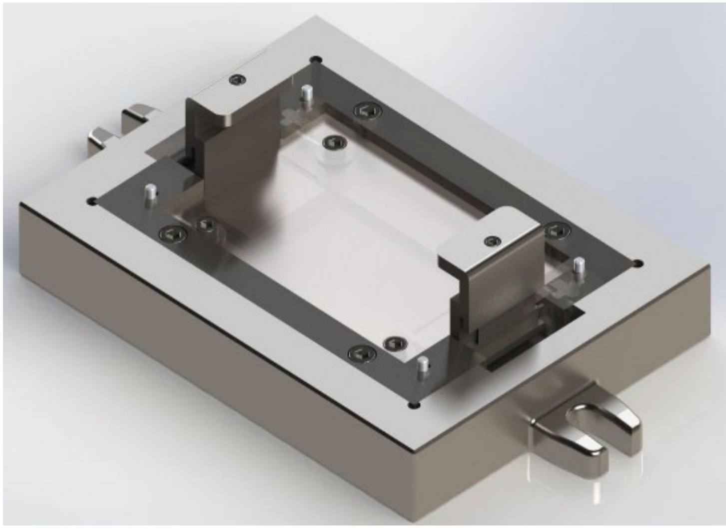

Figure 1: 3D model of spring-loaded fixture.

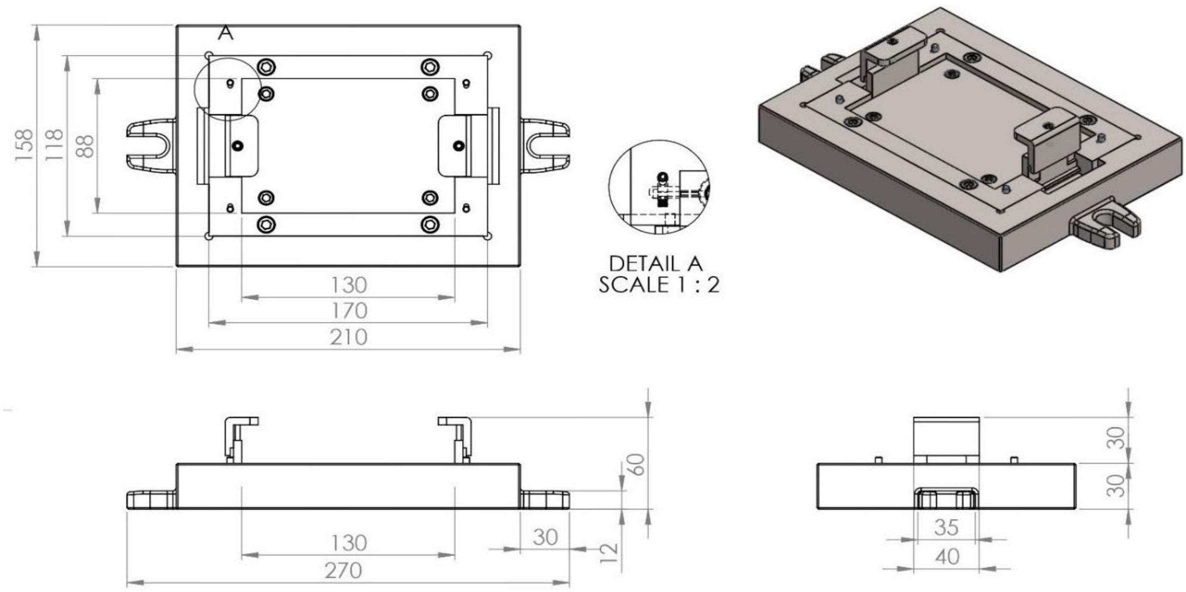

Figure 2: Dimensions of spring-loaded fixture.

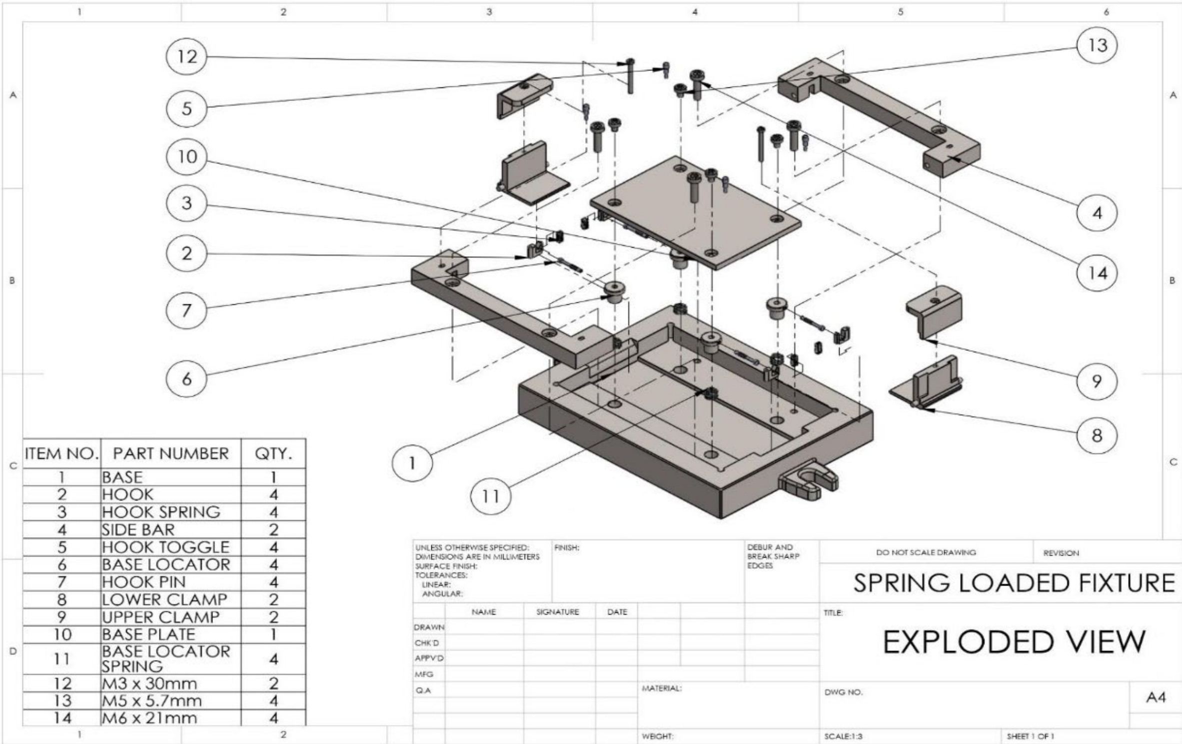

Figure 3: Exploded view of the spring-loaded fixture.

2.2 Manufacturing Process

The fabrication process for screw-based assembly fixtures consists of several critical steps designed to meet the project's goals of precision, efficiency, durability, and versatility. The process begins with detailed design and engineering, utilizing advanced CAD (Computer-Aided Design) software to create precise plans for the fixtures. Key considerations in this phase include selecting appropriate materials, optimizing component placement for alignment, and incorporating automation-friendly features where necessary.

Material selection is a crucial aspect of the process, as high-quality materials are chosen based on their strength, durability, and compatibility with the intended application. Common materials for this project include aluminum alloys, stainless steel, and engineering plastics, all of which are valued for their mechanical properties and corrosion resistance.

Precision machining techniques are then employed to manufacture the various components of the fixtures, ensuring tight tolerances and smooth surface finishes. CNC (Computer Numerical Control) machining processes, such as milling, turning, and drilling, are utilized to maintain consistent accuracy in component dimensions.

Once the components are fabricated, they are assembled according to the design specifications. Particular attention is given to alignment and fitment, ensuring that the fixtures operate smoothly and effectively. In cases where the fixtures are designed for integration with automated assembly systems, additional steps are taken to incorporate automation-friendly features, such as the installation of sensors, actuators, and other necessary components for seamless interaction with robotic arms or conveyor systems.

Following assembly, the fixtures undergo a series of testing procedures to verify their functionality, precision, and durability. Quality control measures, including dimensional inspections, load testing, and endurance testing, are implemented to ensure that the fixtures meet or exceed the required performance standards.

The final stage of the process involves finishing and surface treatment to enhance the appearance and durability of the fixtures. This includes processes like deburring, polishing, and applying surface coatings. Surface treatments such as anodizing, plating, or powder coating may be used to improve corrosion resistance and provide a professional finish.

3. RESULTS AND DISCUSSION

3.1 Computer-Aided Manufacturing

Using Computer-Aided Manufacturing (CAM) techniques with MasterCAM software, we explain the procedures that are involved in the product development process. Among these are the selection of tools, the establishment of cutting settings according to the material being worked with, and the creation of a comprehensive setup sheet for machining operations. To achieve efficient and effective machining with computer-aided manufacturing (CAM) software, it is vital to have a full awareness of the stages and considerations that have to be taken.

Figure 4: Sidebar.

For machining to produce the required results of the part as shown in Figure 4, tool selection is an extremely important step. The tools listed in Table 1 were chosen for the operations according to their specifications and the fact that they were suitable for the tasks.

Table 1: List of tools.

Tool No.	Description	Diameter (mm)	Application
1	Carbide Insert Mill	50	Facing
2	HSS Endmill	5	Contouring
3	HSS Endmill	4	Pocketing
4	HSS Endmill	3	Pocketing
5	HSS Endmill	2	Slotting
6	HSS drill	6.6	Drilling

3.1.1 Cutting parameter

The cutting parameters in Table 2 summarize the operational settings for various machining processes. Face milling, with the highest cutting speed of 119.84 m/min, is the fastest operation, completing in 9 minutes 39 seconds. Pocket milling has varying feed rates and spindle speeds, resulting in cycle times ranging from 1 minute 40 seconds to 1 hour 20 minutes, depending on tool and depth. Slot milling has the highest feed rate and spindle speed, finishing in 1 minute 46 seconds. Drilling, with moderate feed and speed, completes in 2 minutes 28 seconds. These parameters ensure optimal tool performance and machining efficiency.

Table 2: Cutting Parameter.

Tool Number	Operation Type	Feed Rate (MMPM)	Spindle Speed (RPM)	Cutting Speed (m/min)	Cycle Time (H:M:S)
1	Face milling	305.2	763	119.84	00:09:39
2	Pocket milling	190.9	1909	29.98	01:20:22
3	Pocket milling	238.7	2387	29.99	00:01:40
4	Pocket milling	238.7	2387	22.49	00:02:20
5	Slot milling	477.4	4774	30.00	00:01:46
6	Drill	208.32	1736	35.97	00:02:28

3.1.2 Cutting simulation

The cutting simulation process begins with setting up the cutting toolpaths and the corresponding parameters calculated during the earlier stages. Once the toolpaths are established, a thorough verification is performed to ensure accuracy and prevent potential issues. After confirming that the toolpaths are correct, the simulation is run using MasterCAM software. This step ensures that no errors or collisions occur during machining, minimizing the risk of tool damage or material wastage and optimizing the overall process. This simulation step is critical for validating the machining process before actual execution, reducing the risk of tool damage or material waste. Figure 5 illustrates the toolpath setup and the simulated workpiece in MasterCAM.

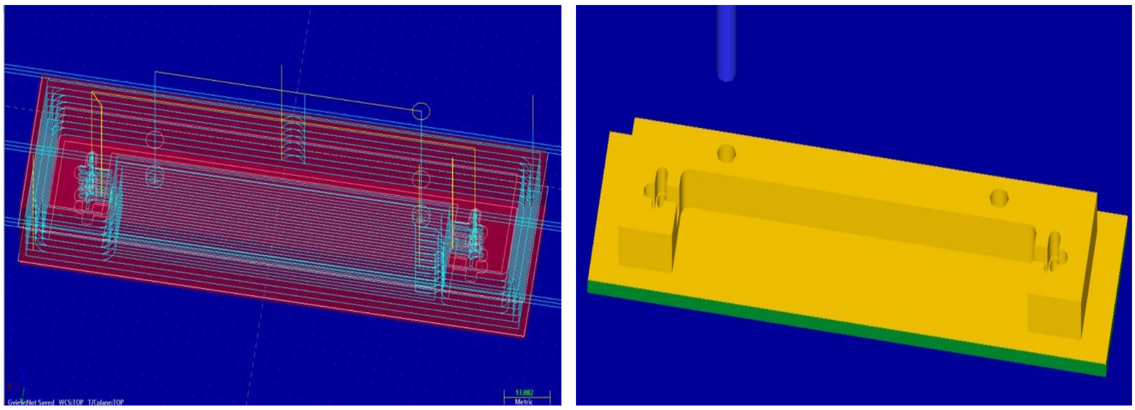

Figure 5: Cutting simulation.

3.2 Direct and indirect cost

Direct costs are expenses directly tied to producing each unit, such as materials and labor. These include the raw materials used and the wages of skilled labor. Indirect costs, however, are not linked to individual units but are necessary for production, like overhead for utilities, administrative expenses, and machine depreciation. Direct costs vary with production volume, while indirect costs are often fixed. Together, they make up the total production cost, affecting overall profitability. In Table 3, the machine costs include a CNC milling machine and lathe, totaling RM 17,000, with annual maintenance of RM 1,700 and a depreciation cost of RM 1.20 per unit for 1,440 units annually. Skilled labor costs RM 100 per unit. Material costs (Table 4) are detailed across 14 components, resulting in a total of RM 367.80 per unit. Overhead costs (Table 5), including utilities and administrative expenses, amount to RM 1,100 per month, with a per-unit overhead cost of RM 9.20 based on an estimated 120 units produced monthly. Taxes, calculated at 10% of direct costs (materials, labor, and overhead), come to RM 47.82 per unit. This provides a full breakdown of production costs per unit.

Table 3: Machine cost.

Type of Machine	Cost	Maintenance Cost/Year
CNC Milling machine	RM 10000	RM 1000/Year
Lathe Machine	RM 7000	RM 700/Year
Total Cost	RM 17000	RM 1700

Machine Depreciation (over 10 years): RM 1700/year (for 1440 units/year, RM 1.20 per unit). The cost for skilled labor is RM100.

Table 4: Material cost.

No.	Component	Qty	Unit Price (RM)	Price (RM)
1	Base	1	55	55
2	Hook	4	3.80	15.20
3	Hook Spring	4	2.5	10
4	Side Bar	2	20	40
5	Hook Toggle	4	3	12
6	Base Locator	4	4	16
7	Hook Pin	4	4.50	18
8	Lower Clamp	2	10.20	20.40
9	Upper Clamp	2	8.90	17.80
10	Base Plate	1	90	90
11	Base Locator Spring	4	5	20
12	M3 × 30 mm	2	2.90	5.80
13	M5 × 5.7 mm	4	4.90	19.60
14	M6 × 21mm	4	7	28
	Total Material Cost			367.80

Table 5: Overhead cost.

Items	Cost (RM)
Utilities:	300 / Month
Administrative Cost:	800 / Month
Overhead per Unit:	
Monthly Overhead:	1100
Estimated Production:	120 Units / Month
Overhead per Unit:	1100/120 units = RM 9.20

Tax: 10% of total direct costs (materials + labor + overhead) (1)
RM 367.8 + RM 100 + RM 1.20 + RM 9.20 = RM 478.20
Taxes per Unit: 10 % of RM 304.59 = RM 47.82

3.2.1 Selling Prices

The selling price of each unit is set at RM 699, based on market rates and the required profit margin. In Table 6, the cost breakdown for each production unit includes RM 367.80 for direct materials, RM 100 for direct labor, RM 1.20 for machine depreciation, RM 9.20 for overhead, and RM 47.82 for taxes. This results in a total cost per unit of RM 526.02. The profit per unit is calculated by subtracting the total cost from the selling price, giving a profit of RM 172.98 per unit.

Table 6: Profit of each production.

Production	Cost
Direct Material	RM 367.80
Direct Labour	RM 100
Machine Depreciation	RM 1.20
Overhead	RM 9.20
Taxes	RM 47.82
Total Cost per Unit	RM 526.02

Selling Price: RM 699
Total Cost: RM 526.02
Profit per Unit: RM 699 – RM 526.02 = RM 172.98

3.2.1 Return of Investment (ROI)

The ROI analysis shown in Table 7 comprises three sections: Initial Investment, Annual Profit, and ROI calculation. The initial investment includes RM 17,000 for machines, RM 529,632 for materials, RM 144,000 for labor, and RM 13,248 for overhead, totaling RM 703,880. For the annual profit, the revenue from selling 1000 units at RM 699 each is RM 1,006,560, while the production cost is RM 757,468.8. This results in an annual profit of RM 249,091.2. The ROI is calculated as shown in equation 3 which is dividing the annual profit by the initial investment and multiplying by 100. This gives an ROI of approximately 35.39%, showing that the investment yields a 35.39% return annually.

Table 7: Return of Investment (ROI).

Initial Investment	
Machines	RM 17000
Materials for 1440 Units	RM 367.80 x 1440 = RM 529632
Labor for 1000 Units	RM 100 x 1440 = RM 144000
Overhead for 1000 Units	RM 9.2 x 1440 = RM 13248
Total Initial Investment:	RM 17000 + RM 529632 + RM 144000 + RM 13248 = RM 703880
Annual profit	
Annual Revenue (1000 units)	1440 x RM 699 = RM 1006560
Annual Cost (1000 units)	1440 x RM 526.02 = RM 757468.8
Annual Profit	RM 1006560 - RM 757468.8 = RM 249091.20

$$\text{ROI} = (\text{Annual Profit} / \text{Initial Investment}) \times 100 \quad (3)$$

$$\text{ROI} = (\text{RM } 249091.2 / \text{RM } 703880) \times 100 \approx 35.39\%$$

3.2 Impact of the product

The project to develop spring-type assembly fixtures represents a significant advancement in manufacturing and assembly operations, offering a variety of benefits that can positively impact various industries. By offering unparalleled precision and accuracy in component alignment, these fixtures aim to transform assembly operations. This will decrease mistakes, rework, and scrap, ultimately improving product quality and customer satisfaction. Moreover, the streamlined assembly processes and reduced setup times facilitated by these fixtures contribute to increased efficiency and productivity in manufacturing operations, leading to higher throughput and improved overall production output.

In addition, the use of ergonomic design elements guarantees the safety and comfort of workers, reducing the possibility of fatigue and repetitive strain injuries. The fixtures are made to resist the stresses of industrial use by utilizing strong design concepts and durable materials. This results in consistent performance over a long period and reduced maintenance requirements. Furthermore, the fixtures are extremely adaptable to changing production demands due to their flexible parts and compatibility with a variety of assembly activities and automation systems, enhancing their versatility in variable manufacturing settings. The goal of this project is to increase accessibility to advanced assembly fixtures for companies of all sizes by providing cost-effective solutions without sacrificing quality, which lowers total costs and improves profitability. Taken together, these fixtures provide a way to improve assembly lines, enhance the quality of products, and boost productivity, setting companies up for long-term success and global competitiveness.

4. CONCLUSION

The research on the development and design of a spring-type fixture demonstrates its significant impact on improving the precision, repeatability, and efficiency of manufacturing processes that require repetitive assembly or testing. Through a detailed design approach, incorporating material selection, dimensional optimization, and cost-effectiveness, the spring-loaded fixture provides a practical and adaptable solution for ensuring consistent workpiece positioning and clamping accuracy. The use of cutting simulations in MasterCAM has further validated the toolpath accuracy, eliminating potential collisions and ensuring operational safety and reliability. The results confirm that the integration of a spring mechanism enhances flexibility and reduces operator errors, leading to improved production throughput in various high-precision industries such as automotive, aerospace, and electronics. Moreover, the cost-efficient design of the fixture makes it a valuable addition to modern manufacturing, offering both performance and economic advantages. This research contributes to the ongoing development of fixture technologies, underscoring the importance of innovative, adaptable, and cost-conscious designs in advancing manufacturing efficiency and product quality.

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