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Reducing Cycle Time in the Manufacturing Process of Circular Pattern Interpolar Products (CPIP) Using Special Fixtures on a 3-Axis CNC Machine

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Abstract— **This research focuses on the design of fixture aids to support the manufacturing process of Circular Pattern Interpolation Products (CPIP), such as disk brake components, flanges, turbine disk runners, and other plate components with circular feeding patterns in the 3-Axis CNC machining process. The objective of this study is to achieve more efficient CPIP production times on 3-Axis CNC machines. The research methodology employed a design and build approach, involving the design of fixture aids, fabrication, and testing during the production of turbine disk runners on a 3-Axis CNC machine. This was done by comparing the initial workpiece setup time and the workpiece clamping transfer time using CPIP production aids versus not using CPIP production aids. The results showed that the designed CPIP Fixture significantly reduced the CPIP manufacturing Cycle Time, with a reduction of 63.11% in the initial workpiece setup time and 83.55% during the clamping transfer process.**

Keywords— Fixture, CNC 3 Axis, Circular Pattern Interpolation Product, Disk Runner

I. Introduction

Currently, manufacturing products are undergoing rapid development in tandem with advancements and innovations in supporting mass production technologies. One of these innovations is the 3-Axis CNC Milling machine, which has made significant strides in processing square block products and working with steel plates. The 3-Axis CNC Milling machine boasts high-quality output and production efficiency. This machine can cut materials with high precision and produce products that closely match the design, all controlled through computer commands [1].

However, some components require specialized treatment in the 3-Axis CNC machine processing. One such category is the Circular Pattern Interpolation Product (CPIP). CPIP comprises circular-shaped products made from flat materials, typically characterized by their outer and inner diameters. Examples of CPIP products include disk brake components, flanges, turbine disk runners, and various plate components. In the CNC 3-Axis machine, the CPIP processing typically involves two stages. First, the circular pattern feeding to create the inner diameter while gripping the outer part of the plate. Second, the clamping transfer to the inner diameter hole area to complete the formation of the outer diameter circle.

In CPIP production, the CNC Milling 3-Axis machine is often not equipped with specialized tools for such unique processing, leading to less effective production times due to waiting for material setup and time-consuming clamping transfer processes. Hence, this process necessitates the design of an effective fixture as a tool that reduces material setup time and serves to secure the workpiece on the 3-Axis CNC machine.

II. Literature Review

A fixture is a tool used to clamp and secure workpieces, typically employed in 3-axis CNC Milling machines to hold workpieces against the load of the CNC machine's axis movements, requiring high

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accuracy, and made from specific materials suitable for the machining process [2].

The creation of fixtures must consider several aspects, including Design (structure, assembly, rigidity), Technology (accuracy, flexibility, productivity, quality), Operational (safety, maintenance, usability), and Economic (main costs, efficiency) [3].

The fixture design process involves multiple stages, including understanding the criteria of the processed product, analyzing the design's strength, evaluating criteria, and fixture methods [4].

In this research, the focus of CPIP fixture design is on turbine disk runner products. A disk runner turbine is a component where circular-shaped blades attach, featuring an inner diameter hole and grooves following the blade pattern. The manufacturing of turbine runner components focuses on meeting shape tolerances while considering properties such as straightness, evenness, roundness, and more [5].

Prior technologies related to turbine component fixture manufacturing have mainly revolved around assembly processes, such as the welding fixture for runner components created by Muchtar et al. in 2018. The results showed a maximum deviation of 1.2 mm and 0.68 mm for the runner plate diameters of 300 mm and 200 mm, respectively. This approach reduced production time while achieving higher accuracy with their designed fixture [5]. Additionally, in 2019, Muchtar et al. introduced a fixture technology for assembling runner and cross-flow turbine casings, which minimized rotational deviation (runout) in the runner and dimensional variations in the cross-flow turbine casing [6].

Some earlier technologies focusing on the formation of CPIP-type disk runners, however, employed conventional cutting methods using oxyacetylene gas flames with kinematic mechanisms [7], as created by Sutanto in 2015. This technology solely concentrated on the formation of disk runners and did not consider dimensional accuracy, potentially increasing turbine runner rotational deviations. Therefore, for CPIP processes emphasizing high dimensional accuracy, it is advisable to use 3-Axis CNC machines with specifically designed fixtures to achieve precise dimensional accuracy.

Various fixture technologies for CNC machines have been developed in the past, some intended for multiproduct manufacturing. For instance, a new construction of modular fixtures introduced by [3] allows for adjustable positioning and clamping of workpieces, enhancing efficiency. These fixtures reduce setup and preparation time, improving production planning efficiency for prismatic and quadrant workpieces. However, they may not be applicable to CPIP due to its unique machining requirements based on feeding patterns. Hence, this state-of-the-art research appropriately addresses fixture technology in CPIP manufacturing.

III. Method & Materials

The design process commences with the fixture design phase. In the design process, several considerations are taken into account, such as the intended fixture environment, including operational processes, workpieces, cutting tools, machinery, and operators. Environmental factors constitute external aspects that influence the structure, assembly, and rigidity of the fixture [3]. These external factors can be observed in Table 1.

The machine specifications encompass critical factors that directly impact the design and performance of the CPIP fixture. The vertical configuration of the machine signifies its primary axis orientation, influencing the fixture's clamping and positioning mechanisms. The dimensions of the machine's working space define the physical constraints for the fixture, affecting its size and design. Factors like the maximum rotational frequency, maximum load capacity of the working table, and the number of axes and cutting tools significantly affect fixture complexity and design. Machine power and positioning accuracy also play pivotal roles in shaping the fixture's structural robustness and precision.

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The workpiece's characteristics are fundamental in fixture design. The geometrical shape dictates how the workpiece is clamped and positioned, making it a key consideration. The workpiece's overall dimensions and weight influence the size and load-bearing capacity of the fixture. Material properties, such as work material, raw material form, material removal volume, and stiffness, guide tool selection, cutting parameters, and fixture material compatibility. Parameters of functional surfaces impact how the fixture grips and secures the workpiece, while heat treatment requirements may necessitate specific fixture materials and designs. Batch size and annual demand inform fixture setup and production efficiency.

Tool-related factors encompass the type of cutting tools used, their parameters (dimensions, angles, material), and cutting modes (feed rates, spindle speeds, tool life). These aspects influence the fixture design by determining provisions for tool changes, tool access, and holder compatibility.

The worker-related considerations involve the qualifications of the operator, ergonomic factors, and safety. Worker qualifications influence fixture design by ensuring ease of use and setup. Ergonomics are crucial for worker comfort and safety during operation. Safety features, such as guarding and interlocks, are integrated into the fixture design to protect workers from potential hazards.

Table 1. External Factors in the Designed Fixture Research

Components of the external environment	**Characteristic**
Machine Specifications	Vertical Configuration Dimensions of working space Maximum rotational frequency Maximum load of working table Number of axes Number of Cutting Tools Machine Power Positioning accuracy
Work Unit	Geometrical Shape Overall dimensions Weight Work material Raw Material Form Material removal volume Stiffness Parameters of functional surfaces (work, locating, clamping) Heat treatment Batch size Annual demand
Tools	Type Parameters (dimensions, angles, material, etc) Cutting modes (feed, speed, tool life, etc) Tool accessibility
Worker	Qualifications Ergonomics Safety

After determining the environmental factors, the next step is to establish the design and construction steps based on Figure 2:

STEP 2 Manufacturing Process Functional Test	**STEP 1** Literature Study Characteristics of external factors Fixture Design
STEP 3 Data Retrieval Data Evaluation	**STEP 4** Conclusion Suggestions for improvement

Figure 1. Design steps

The design is carried out in accordance with these external factors using Computer-Aided Design (CAD) software, in this case, Autodesk Inventor 2021. Here are the results of the CPIP fixture design.

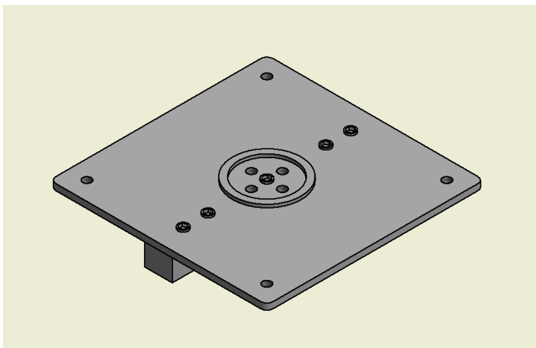

Figure 2. *Fixture* CPIP Design

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The process of creating the CPIP fixture involves the use of ST 37 steel plates measuring 370 mm × 370 mm × 15 mm and square steel rods measuring 50 mm × 50 mm × 370 mm, along with M10 bolts as adjusters. The manufacturing process begins by flattening the steel plate until it reaches the size of 350 mm × 350 mm with an inner circular groove of 90 mm in diameter and an outer diameter of 110 mm, all with a height of 15 mm. Following the facing process, several holes are drilled to accommodate the adjusters, and then the assembly is performed using clamping rods. The components before and after manufacturing can be observed in Figures 3 and 4.

a. b.

Figure 3. Clam Rod *(a. before b. after)

a. b.

Figure 4. *Support* Plate *(a. before b. after)

Testing and data collection for the CPIP fixture are conducted by comparing the processing time of CPIP - turbine disk runners on a 3-Axis CNC machine, which includes initial workpiece setup, inner diameter manufacturing, clamping transfer, and groove creation. This comparison is performed with the same operator across three experimental trials.

After collecting the data, the time difference is calculated using the formula [8]:

$$CT = CT\ without\ using\ fixture\ - CT\ using\ CPIP\ fixture \quad (1)$$

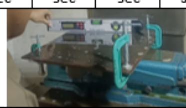
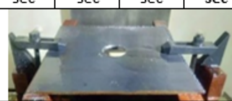
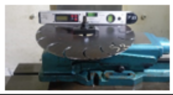
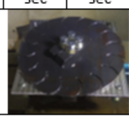
$$CT\ percentage = (CT\ /\ CT\ without\ using\ features)\ x\ 100\% \quad (2)$$

CT = Cycle Time

IV. Results and Discussion

After conducting tests on the CPIP fixture, the following data was obtained, as shown in Table 2:

Table 2. Results of Testing and Data Collection for the CPIP Fixture

Keterangan	Menggunakan Alat Bantu				Tanpa Menggunakan Alat Bantu			
	I	II	III	**Rata-rata**	I	II	III	**Rata-rata**
SETTING AWAL BENDA KERJA	150.96 sec	155.65 sec	148.51 sec	**151.70 sec**	453.42 sec	402.13 sec	378.16 sec	**411.23 Sec**
								
PROSES DIAMETER DALAM	184 sec	184 sec	184 sec	**184 sec**	184 sec	184 sec	184 sec	**184 sec**
								
PEMINDAHAN CLAMPING	155.93 sec	150.92 sec	156.69 sec	**154.51 sec**	981.07 sec	924.36 sec	913.20 sec	**939.54 sec**
								
ALUR PEMBUATAN DISK RUNNER	2,065 sec	2,065 sec	2,065 sec	**2,065 sec**	2,065 sec	2,065 sec	2,065 sec	**2,065 sec**
								

The *Cycle Time* graph can be seen in Figure 4 below:

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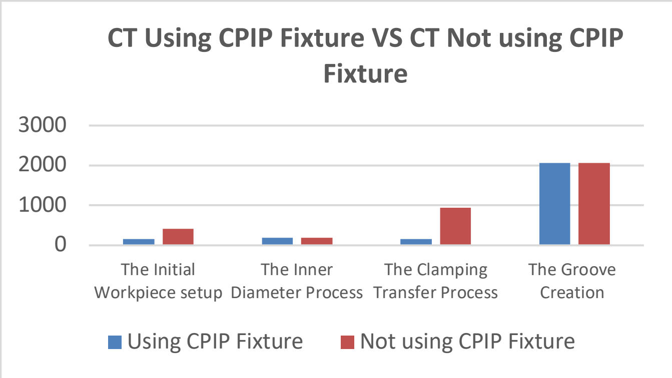

Figure 4. *Cycle Time chart* using CPIP Fixture and without CPIP Fixture

In Figure 4, a noticeable difference in the CT (Cycle Time) values can be observed. The CT difference is 259.53 seconds during the initial workpiece setup and 785.03 seconds during the clamping transfer process. Meanwhile, the processing times for the inner diameter and groove creation remain constant at 0 seconds. This constancy is due to the nature of these processes.

The CT percentages for the initial workpiece setup and clamping transfer are 63.11% and 83.55%, respectively. This indicates that the use of the fixture reduces the time required in the CPIP - Disk Runner Turbine production process.

Among the two stages of CPIP - Disk Runner Turbine production, the clamping transfer process exhibits a significantly notable impact, with an 83.55% reduction in CT. This reduction is attributed to the fact that without the CPIP fixture, the operator would need to reconfirm reference points on the 3-Axis CNC machine and adjust machine parameters. However, with the CPIP Fixture, the operator no longer needs to perform reference point adjustments.

The results of this study align with the research conducted by [8], titled "Fixture Design to Reduce Production Costs for KCJR and KCJL Levers," where the fixture design reduced CT by 58% in a 3-axis CNC drilling process [8]. Additionally, this study is consistent with the research conducted by [3] on "Flexible Fixture for CNC Machining Centers in Multiproduct Manufacturing." Their findings confirmed that machining processes involving drilling and milling for various workpieces, including prismatic and rotational parts, could be efficiently executed with fixtures [3]. Similarly, this study assures that CPIP processes can be performed efficiently with the designed fixture.

V. Conclusion

Based on the conducted study, it can be concluded that the CPIP Fixture design significantly reduces the Cycle Time of CPIP - Disk Runner Turbine production. The CT reduction is 63.11% during the initial workpiece setup and 83.55% during the clamping transfer process. These results confirm that CPIP processes can be performed using the designed fixture, reducing cycle time. Consequently, it is expected that this efficiency will lead to savings in production costs, including material and energy consumption, in the future.

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