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Core Mold Machinery Optimization Process CNC Milling Machine

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Abstract

Global competition for the same product segmentation, companies need to innovate and optimize the products they produce. One of the optimizations carried out is by improving the machining process in the manufacture of mold components. The program creation process is carried out using Computer Aided Manufacturing (CAM) software from Delcam (PowerMill 2020) which is then used on CNC Milling machines. An improvement process is needed for making a CAM program so that production quality continues to meet standards and the production process time becomes more effective. To optimize the mold production process, reduce mold production costs, maintain the quality of the resulting production. By collecting data obtained by interacting directly with irrational parties, conducting experiments and directly observing the operational processes carried out in research, so as to understand the problems, critical points in the field. There are several factors that have an impact on research, namely on the quality that the quality of the product when viewed from the stock model is smooth and according to standards. Then delivery (Delivery) reduced machining time or cycle time on Core parts will provide reciprocal delivery to the next process at a more appropriate time. For the safety of the Computer Aided Manufacturing (CAM) program and the use of overhangs, if verified using PowerMill Software, no collisions or program crashes were found. It can be ascertained that the manufacturing program in this study is safe to use and the productivity obtained is more optimal.

Keywords: CAM (Computer Aided Manufacturing); CNC (Computer Numerical Control); PowerMill; Toolpath Strategy; Machining Time

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INTRODUCTION

In the current business environment, characterized by heightened competition and an expanding number of market participants, it has become imperative for companies to intricately understand and effectively cater to the evolving needs and desires of consumers [1]. This necessity is driven by the requirement to not only meet but exceed consumer expectations in ways that distinguish a company from its competitors. To achieve this, companies must adopt a consumer-centric approach that prioritizes thorough market research to accurately gauge consumer preferences and trends [2]. This insight enables companies to tailor their products and services to better align with consumer demands, thereby enhancing customer satisfaction and loyalty. As consumer preferences can shift rapidly, continuous monitoring and adaptation are essential, ensuring that the companies remain relevant and preferable in the eyes of their target market [3], [4].

Furthermore, in the quest to outperform competitors, it is crucial for companies to focus on the development of high-quality and attractive products. This involves a meticulous design and development process that emphasizes innovation, aesthetic appeal, and functionality, all of which are significant to today's discerning consumers [5]. Quality assurance processes must be stringent, ensuring that all products meet a high standard before reaching the market, thereby reducing the risk of customer dissatisfaction and potential damage to the company's reputation [6]. Moreover, companies must continually strive to enhance their operational efficiencies and performance. This could include investing in advanced technologies, adopting lean manufacturing processes, or enhancing supply chain logistics. Such improvements can lead to better product quality, lower production costs, and faster delivery times, which are all critical factors in winning over consumers and gaining an edge over competitors [7].

In the face of global competition, particularly within the same product segmentation, the necessity for continuous innovation and optimization cannot be overstated [8]. Companies must invest in research and development (R&D) to foster innovation, enabling the creation of new products or the enhancement of existing ones with unique features that meet the unarticulated or future needs of consumers. This proactive approach in innovation can lead to the development of proprietary technologies or products that not only set a company apart from its competitors but also potentially define new standards in the industry [9]. Additionally, the optimization of product lines to maximize efficiency and minimize waste is crucial. This not only impacts the bottom line positively by reducing costs but also enhances the company's sustainability practices, making it more attractive to environmentally conscious consumers [10]. Hence, innovation and optimization are fundamental in securing a competitive advantage and ensuring long-term success in a globalized market [11].

One of the primary strategies for optimizing manufacturing processes involves enhancing the machining operations used to create components for molds. This optimization is critical as the quality and precision of these components directly influence the efficiency and effectiveness of the production cycle. To achieve this, a comprehensive analysis is undertaken, starting with the product design, followed by the manufacturing processes, and culminating with the assembly operations [12]. Such an analysis helps in identifying potential inefficiencies or areas for improvement in the production line, ensuring that each component is manufactured to meet exacting standards. This rigorous approach not only minimizes material waste and reduces production time but also significantly improves the overall quality of the final product [13]. By refining these processes, companies can achieve greater control over the production environment, leading to consistent and high-quality outputs [14].

In the realm of manufacturing optimization, the creation of machining programs represents a pivotal aspect. This process is facilitated by the use of advanced software tools, such as Computer Aided Manufacturing (CAM) software from Delcam, notably PowerMill 2020 [15]. CAM systems are instrumental in translating three-dimensional image designs into precise machining directives in the form of numerical control (NC) program language. This technology bridges the gap between digital design and physical manufacturing by enabling the precise control of machine tools via computer systems, known as CNC (Computer Numerical Control) [16]. By leveraging such sophisticated software, manufacturers can enhance the accuracy and efficiency of the machining process. This not only ensures that components are produced with the highest fidelity to the original designs but also optimizes the use of materials and reduces the time taken for production [17].

Furthermore, the adoption of CAM and CNC technologies in manufacturing underscores a significant shift towards automation and precision engineering. These technologies allow for the automation of complex and repetitive tasks, which not only accelerates the manufacturing process but also mitigates human error [18], [19]. The use of CNC machines, programmed through CAM software, enables manufacturers to execute intricate and precise cuts that would be challenging and time-consuming to accomplish manually. This level of automation and precision is essential in industries where the complexity of components and the demand for accuracy are high, such as aerospace, automotive, and precision electronics manufacturing [20], [21]. Additionally, the integration of these technologies into production processes helps in maintaining competitive advantages by ensuring faster production times, higher-quality outputs, and greater flexibility in manufacturing operations. This strategic approach to manufacturing not only enhances product quality but also boosts the company's capacity to meet rapidly changing market demands [22]–[24].

The quality and duration of the production process are fundamentally influenced by the efficacy of the CAM (Computer Aided Manufacturing) programs developed by the programmers. Given this critical relationship, enhancing the process of creating CAM programs is imperative to ensure that production quality adheres to predefined standards and that the production timeline is optimized for effectiveness[25], [26]. The refinement of CAM programming involves a detailed evaluation and revision of existing algorithms to reduce errors and inefficiencies. Advanced programming techniques and the integration of real-time data analytics into the CAM system can lead to more precise machining instructions, minimizing the scope for human error and material wastage. This systematic improvement in CAM programming directly impacts the production floor, where precision and adherence to timelines are paramount[27], [28]. As such, continuous updates and training in the latest software capabilities become essential for programmers, ensuring that the manufacturing process not only meets quality standards but also does so within the shortest possible timeframes[29], [30].

Furthermore, the strategic enhancement of CAM programs has broader implications for the overall manufacturing operations. By optimizing these programs, companies can significantly shorten cycle times and enhance product quality, leading to increased customer satisfaction and a stronger competitive edge in the market[31], [32]. Implementing best practices in CAM programming, such as modular programming and the use of simulation tools, allows for rapid adjustments and fine-tuning of production processes. Simulation tools, in particular, offer a powerful advantage, enabling programmers to test and refine CAM programs in a virtual environment before actual production begins. This proactive approach minimizes costly downtimes and material wastage during production[33], [34]. Moreover, the ongoing advancement in CAM technology, including machine learning algorithms, provides opportunities to automate the optimization of machining parameters in real-time, adapting to variations in material properties and tool wear. Ultimately, these improvements in CAM programming contribute to a leaner, more dynamic manufacturing process, where quality and efficiency are continually enhanced to meet evolving market demands and production goals[35].

The primary objective of this research is to enhance the efficiency of the mold production process by identifying and implementing strategies that can reduce production costs while concurrently ensuring the maintenance of high-quality outputs. By meticulously analyzing each stage of the mold production workflow, this study aims to uncover potential inefficiencies and propose cost-effective solutions without compromising the quality of the final product. This balanced approach seeks to optimize resource utilization and streamline operations, thereby delivering both economic and qualitative benefits to the manufacturing process.

METHODOLOGY

In this research, data collection techniques play a crucial role in gathering the necessary information to address the posed research questions. The methodology primarily involves the interview method, where data is collected through direct interactions with key participants. These include employees responsible for operating a 3-axis milling machine at the Machining Center, who handle tasks such as core mold processing, and programmer employees who create CAM programs for milling and turning machines using PowerMill 2020 software. Additionally, the observation method is utilized, enabling the direct collection of data in the field. This approach facilitates an in-depth understanding of onsite problems and allows for the observation of critical operational processes within ongoing work. The research employs both primary and secondary data. Primary data is directly gathered from individuals involved in the Die Shop Department, encompassing elements such as designs, cutting tools, machine parameters, and more. Conversely, secondary data is sourced from external parties, primarily consisting of literature from journals that support the research. Data processing in this study is aimed at identifying potential causes of problems through methodological discussions and idea exchanges. These discussions help categorize issues into several broad groups—namely the 5 M's (man, machine, method, materials, measurements) and 1 E (environmental)—which are further explored through opinion exchanges and discussions. The research setting is PT. Javas Paraduta Technology, where data is procured through field studies supplemented by literature reviews. The data encompasses various aspects such as machining cost, process time, material specifics, imagery, cutting tool details, and machine data utilized in the research.

In the present study, the material selected for the core component is S45C, a medium strength carbon steel that conforms to the Japan Industrial Standards (JIS). This choice is illustrated in Figure 1, which depicts the specific shape of the S45C core utilized in the experiments. As a commonly employed material in industrial applications, S45C is favored for its balance of strength, machinability, and hardness. The distinct characteristics of S45C steel, including its tensile strength, yield strength, and elongation properties, are comprehensively detailed in Table 1. These properties make S45C an ideal candidate for rigorous industrial applications requiring durability and precision.

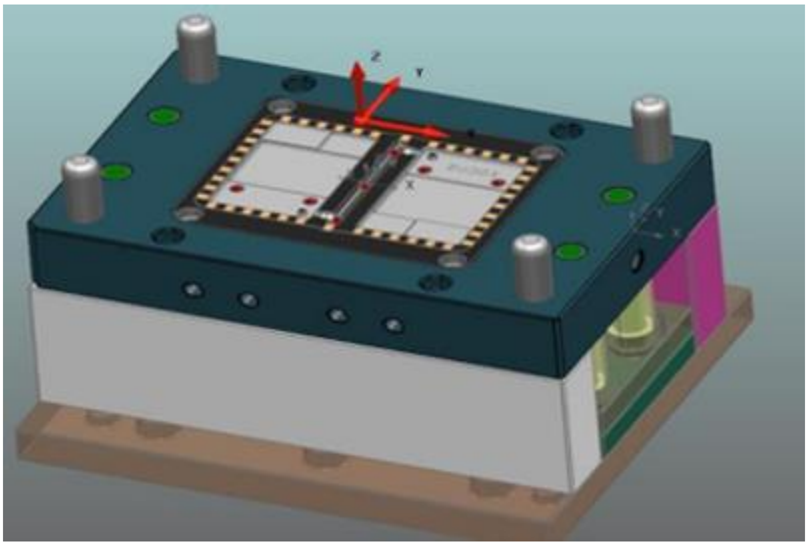

Figure 1: Core

Table 1: Specification of Material S45C

Properties	Value	Unit
Elasticity Modulus	200000	N/mm^2
Shear Modulus	0.26	N/mm^2
Density	7800	kg/m^3
Tensile Strength	680	N/mm^2
Yield Strength	420	N/mm^2
Thermal expansion coefficient	1.1e-005	/K
Thermal Conductivity	14	W/(m.K)
Thermal Specification	440	J/(kg.K)

The Mori Seiki CNC machine, a pivotal asset at PT. Javas Paraduta Technology, stands as a specialized machining center designed to handle workpieces with intricate geometries and stringent precision requirements. Renowned for its robust performance and advanced technology, this machine enables the precise fabrication of complex components, thereby ensuring high-quality outcomes. It is particularly adept at meeting the demanding standards required in sectors such as aerospace, automotive, and precision engineering. Detailed specifications of the Mori Seiki CNC machine, including its operational capacity, speed, tooling system, and accuracy, are systematically presented in Table 2. This information highlights the machine's capabilities and its critical role in the manufacturing processes at PT. Javas Paraduta Technology.

Table 2: Specifications of the Mori Seiki CNC Machine

Specification of Machine	
Type	NV 4000 G
Table Size (mm)	700 x 450
X-axis Travel (mm)	600
Y-axis Travel (mm)	400
Z-axis Travel (mm)	400
Table Surface to Spindle (mm)	80-585
Feed Rate (mm/min)	1-20000
Spindle Speed (rpm)	20000
Spindle Taper	BT40
Tool Magazine Capacity	22(24)
Spinde Motor Power (kW)	11/7.5
Dimension (mm)	2800 x 2350 x 2800
Weight (kg)	350

The insert cutter, utilized predominantly in the roughing process of machining, represents a critical tool for removing large amounts of material efficiently. In this research, the chosen cutter is from the Pramet high feed line, characterized by its 25 mm diameter, which ensures optimal performance in heavy cutting conditions. The accompanying holder is of the Pramet brand, model type SBN10, which is specifically designed to maximize stability and minimize vibration during operation. Furthermore, the type of insert employed is BNGX 10, known for its durability and precision in cutting. Figure 2 in the document illustrates the specific design and configuration of the insert cutter used, highlighting its unique attributes and suitability for demanding machining tasks.

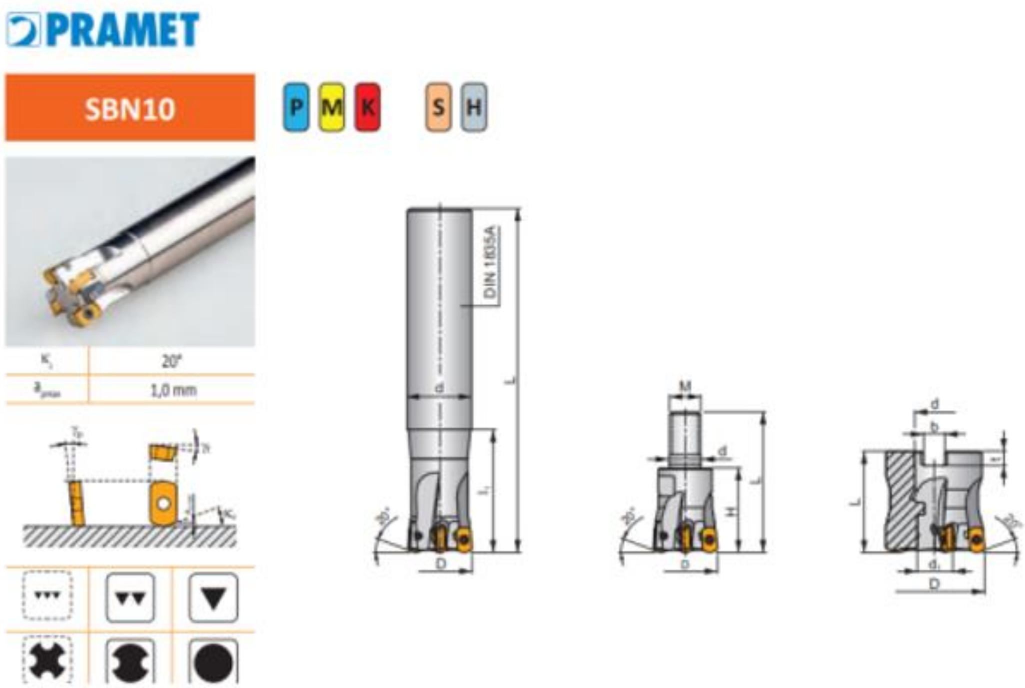

Figure 2: Insert cutter from the Pramet brand type SBN10 and insert type BNGX 10

In this research, ballnose cutters, which feature a radius at the end of the cutting edge mirroring the diameter of the cutter, were integral to the machining processes undertaken. Specifically, six different sizes of ballnose cutting tools were employed to achieve varying levels of detail and surface finish. The sizes used include ballnose cutters with diameters of 16 mm, 10 mm, 8 mm, 6 mm, 4 mm, and 3 mm. These tools are essential for producing smooth, contoured surfaces in components that require high precision. Figure 3 provides a visual representation of the ballnose cutters utilized, showcasing their unique radius-shaped ends which are pivotal for intricate machining tasks. This assortment of cutters enables the achievement of precise geometrical accuracies in a diverse range of materials.

Figure 3: Ballnose cutters

In this study, the utilization of EONONTRIM C385MS coolant is highlighted, featuring the latest advancements in ester technology which significantly enhance both the usability and maintenance of this cutting fluid, thereby optimizing overall machining performance. This coolant integrates a sophisticated blend of synthetic esters and halogens, pivotal for its high-efficiency lubrication properties at the cutting point. The strategic formulation not only reduces thermal buildup but also minimizes wear on cutting tools, thereby extending their operational lifespan and maintaining consistent performance throughout extensive machining operations. The advanced ester technology embedded in EONONTRIM C385MS plays a crucial role in improving the thermal conductivity and lubricity of the coolant, which directly contributes to achieving finer surface finishes and precise dimensional accuracy in machined parts. The improved chemical stability of the coolant also reduces the frequency of changes needed, leading to lower disposal costs and enhanced environmental sustainability. Detailed technical data outlining the specific properties and performance metrics of EONONTRIM C385MS coolant is systematically presented in Table 3. This includes its viscosity, boiling point, pH level, and other relevant characteristics that underscore its superior performance capabilities in a variety of machining contexts.

Table 3: Specifications of Coolant EONONTRIM C385MS

Technical Data	
Appearance	Blue Liquid
Color (working solution)	Clear
Odor	Mild anime
Specific Gravity	1.040±0.03
Typical operating pH	9.0-10
Flash Point	> 100 ^{o}C
Refractive Index	2.5

RESULT AND DISCUSSION

Toolpath Strategi Analysis

In this study, the toolpath strategy for the roughing process incorporates the Area Clearance Model and Rest Area Clearance Model. For the finishing process, a detailed comparative analysis is conducted on the selected toolpaths, namely 3D Offset Finishing, Optimized Constant Z Finishing, and Steep and Shallow Finishing. These strategies are simulated on an identical workpiece, with specific parameters set for spindle rotation (6400 rpm), feed rate (1500 mm/min), and depth of cut (0.4 mm). The analysis of these toolpath strategies indicates that Steep and Shallow Finishing is the most effective for semi-finishing and finishing processes. This strategy offers the flexibility to adjust the depth of cut for different sections of the workpiece, such as walls and floors. Additionally, it supports two types of cutting directions—3D Offset and raster—which aids programmers in enhancing the workpiece contour quality.

Toolpath Strategy Core Optimalization

The optimization of core work process improvements is rigorously implemented in the pre-heat treatment (BHT) stages of the machining process. Figure 4 presents a schematic of the optimization strategy for the roughing, rest roughing, and semi-finishing stages. This approach enhances these processes by focusing on the selection of cutting tools, their associated parameters, and the condition of the machinery employed. Optimization of the toolpath strategy for the core section involves maximizing parameters such as depth of cut, spindle rotation, and feed rate. The machining process for the core, prior to heat treatment, encompasses stages of roughing, repeated rest roughing using a Ø16 cutter, and semi-finishing.

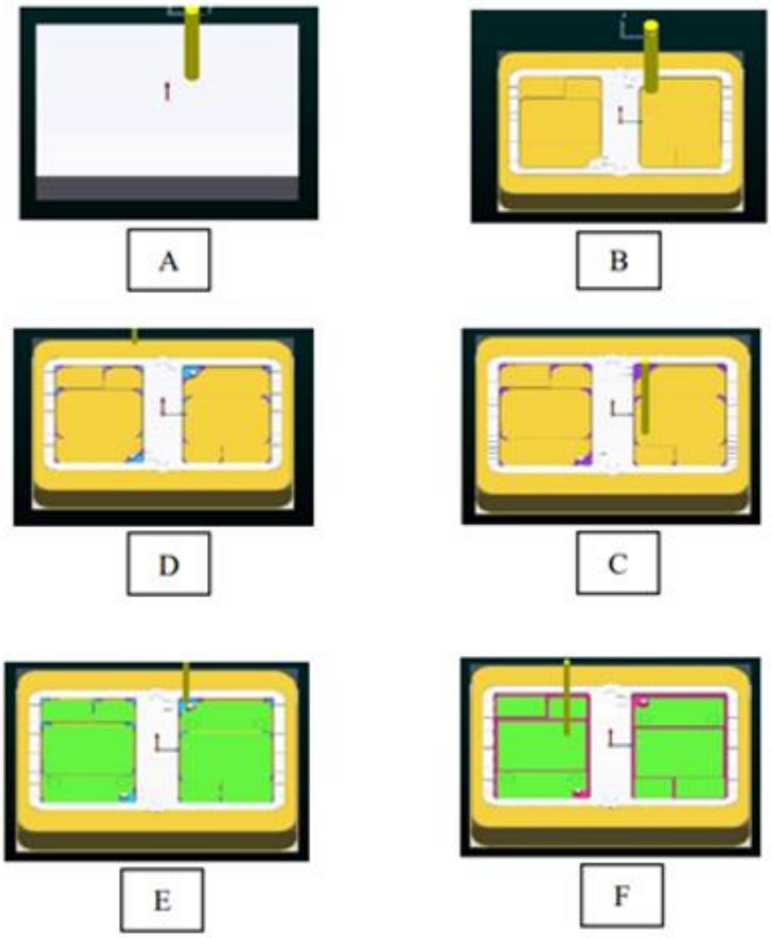

Figure 4: Optimization strategy: (a) Raw Material, (b) Roughing, (c) Rest Roughing Ø16, (d) Rest Roughing Ø10, (e) Rest Roughing Ø10 Hub, (f) Semi Finishing

The roughing process on the core component is conducted using a toolpath model area cleaning strategy. Figure 5 illustrates the settings for the Toolpath Roughing parameters prior to optimization. The cutting tool employed is a BNGX 10 Pramet insert cutter, with a step-down of 0.3 mm. The spindle operates at a rotation of 2500 rpm and a feed rate of 5000 mm per minute. Experiments conducted utilizing PowerMill software have yielded results, taking into account the condition of the machine which includes a spindle rotation of 2500 rpm and a feed rate of 5000 mm per minute, thereby setting the cutting depth at 0.5 mm. Figure 6 displays the roughing toolpath parameters following optimization. A comparison of the toolpath strategy processing times reveals that the duration before optimization was 20 minutes and 31 seconds, whereas after optimization, it reduced to 14 minutes and 11 seconds. This results in a time saving of 6 minutes and 21 seconds in the processing time due to the toolpath strategy.

The initial roughing of the break employs a toolpath model with a break area cleaning strategy using a Ø16 ballnose cutter. The parameters include a stepover of 3.2 mm and a stepdown of 0.3 mm. A spindle rotation of 10,000 rpm and a feed rate of 2000 mm per minute are used. Figure 7 illustrates the roughing test parameters on the toolpath prior to optimization. Figure 8 presents the optimized toolpath strategy parameters for the rest area clearance model, which involved adjusting the stepdown parameter to 0.4 mm. The spindle rotation remains at 10,000 rpm, and the feed rate continues at 2000 mm per minute. Post-optimization, the machining time was recorded at 22 minutes and 1 second. A comparison of the toolpath strategy reveals that before optimization, the processing time was 30 minutes and 11 seconds; following 127 optimizations, it was reduced to 12 minutes and 22 seconds. This optimization resulted in a time saving of 17 minutes and 49 seconds.

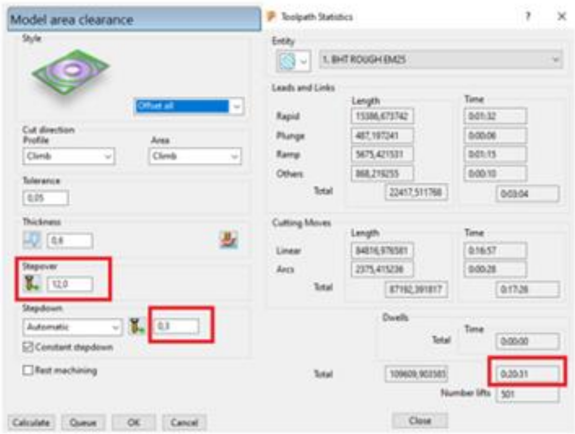

Figure 5: Roughing Toolpath Parameters Before Optimization

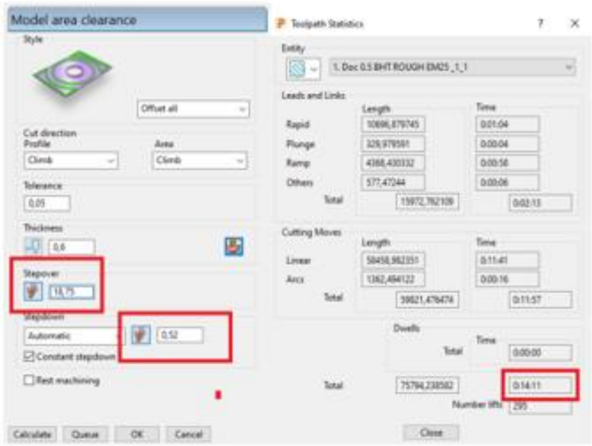

Figure 6: Toolpath Roughing Parameters After Optimization

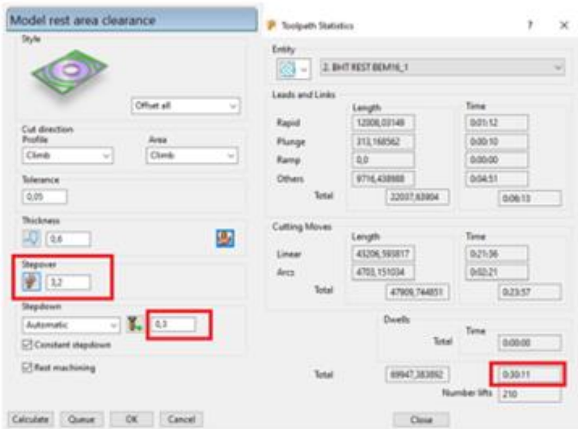

Figure 7: Toolpath Rest Roughing Parameters 1 Before Optimization

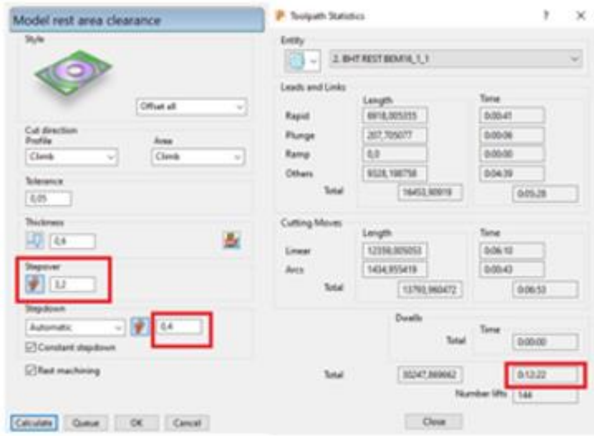

Figure 8: Toolpath Rest Roughing Parameters 1 After Optimization

Figure 9 illustrates the process of hardening the second residual roughing, employing a rest area clearance strategy on the toolpath model using a Ø10 ballnose cutter. The parameters include a stepover of 2 mm and a stepdown of 0.3 mm. A spindle rotation of 10,000 rpm and a feed rate of 2000 mm per minute are utilized. Figure 10 displays the optimized toolpath strategy parameters for the rest area clearance model, which involved adjusting the stepdown parameter to 0.4 mm. The same spindle rotation of 10,000 rpm and feed rate of 2000 mm per minute are maintained. After optimization, the machining time for using this toolpath strategy was recorded at 13 minutes and 55 seconds.

The comparison of the toolpath strategy before and after optimization revealed a processing time of 18 minutes and 39 seconds prior to optimization, and 13 minutes and 40 seconds afterwards. This represents a reduction in processing time of 4 minutes and 49 seconds. The third roughing operation utilizes a toolpath strategy model for cleaning the residual area with a Ø10 ballnose cutter. This cutter has a longer overhang of 65 mm, tailored specifically for contouring the hub. Figure 11 illustrates the parameter settings adjusted to a stepover of 1.5 mm and a stepdown of 0.15 mm, accommodating the considerable overhang length of 65 mm. Given these conditions, these parameters are deemed most effective for roughing operations. A spindle rotation of 10,000 rpm and a feed rate of 2000 mm per minute are employed. Further discussion of tool parameters is provided below, and the machining time for this toolpath is recorded at 6 minutes and 39 seconds.

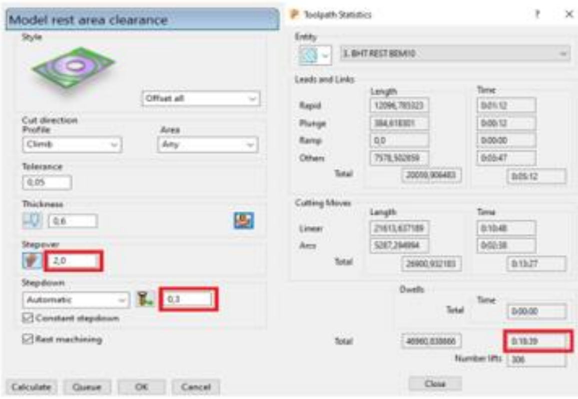

Figure 9: Toolpath Rest Roughing Parameters 2 Before Optimization

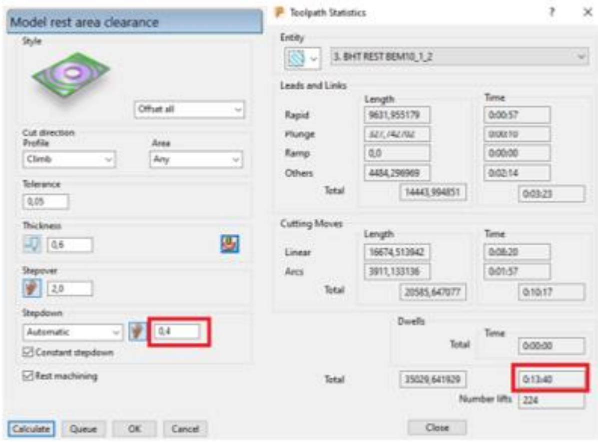

Figure 10: Toolpath Rest Roughing 2 Parameters After Optimization

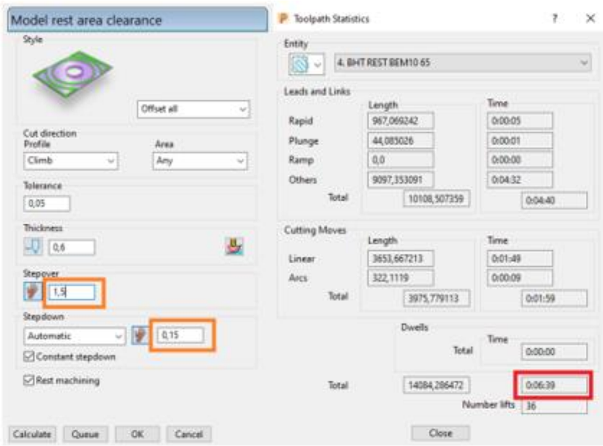

Figure 11: Toolpath Rest Roughing Parameters 3

Semi Finishing Process

The toolpath strategy implemented in the semi-finishing process, as devised by the programmer, incorporates steep and shallow finishing techniques, accompanied by a normal arc surface for both lead in and lead out. The semi-finishing was performed twice, utilizing cutters with differing overhangs. The contour during semi-finishing employed a 45 mm overhang, whereas the hub used a 65 mm overhang. Figure 12 demonstrates that the parameters for the semi-finishing scallop contour, specifically the stepover and stepdown, are set at 0.005 mm, using a Ø10 ballnose cutter. The spindle operates at a rotation of 10,000 rpm, and the feed rate is maintained at 2000 mm per minute.

Figure 13 illustrates the optimization parameters executed using the identical toolpath strategy, but incorporating vertical arcs for both lead-in and lead-out. According to the surface roughness tolerance table, the N6 category specifies a maximum tolerance value of 0.008 mm. Therefore, the maximum scallop height for the floor area is set at 0.008 mm, and for the wall area at 0.01 mm, utilizing a Ø10 ballnose cutter. The spindle operates at a rotation of 10,000 rpm with a feed rate of 2000 mm per minute.

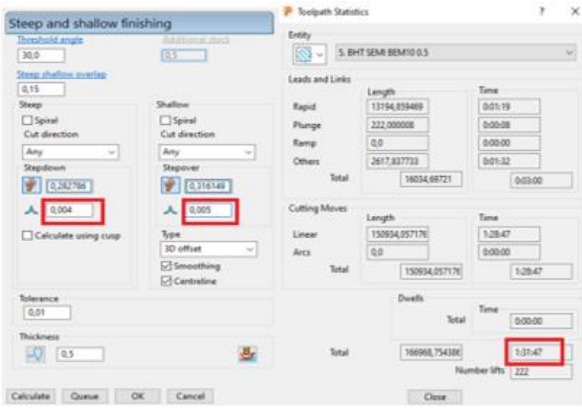

Figure 12: Semi Finishing Toolpath Parameters Before Optimization

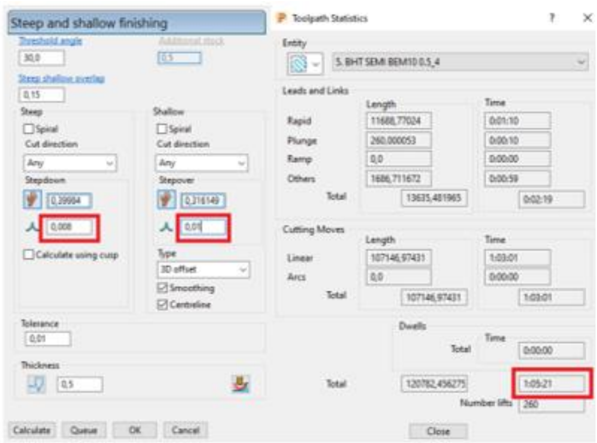

Figure 13: Semi Finishing Toolpath Parameters After Optimization

Table 4 presents a comprehensive comparison of the core processing times before and after heat treatment. The optimization of the toolpath strategy resulted in a reduction of the processing time for core components by 56 minutes and 26 seconds, from 3 hours, 2 minutes, and 13 seconds to 2 hours, 5 minutes, and 47 seconds.

Table 4: Core Runtime Comparison Table

Strategy	Before	After
Roughing	00:20:32	00:14:11
Rest Roughing 1	00:31:02	00:12:22
Rest Roughing 2	00:18:39	00:13:40
Rest Roughing 3	00:06:39	00:06:39
Semi Finishing 1	01:31:47	01:05:21
Semi Finishing 2	00:13:34	00:13:34
Total	03:02:13	02:05:47

CONCLUSION

This research effectively improved the mold production process by strategically decreasing production costs and enhancing efficiency while ensuring the quality of outputs remained uncompromised, aligning perfectly with the initial objectives. Detailed analysis pinpointed several inefficiencies, allowing for refined resource management and more streamlined operational workflows. The interventions retained high product quality, verified by the smoothness of stock models in PowerMill Software, reflecting adherence to industry standards. These modifications led to a substantial reduction in machining time for core parts—from 183 to 126 minutes—resulting in annual cost savings of IDR 24,135,350. Furthermore, the reduction in cycle times facilitated more timely delivery to subsequent stages of the production process, boosting overall workflow efficiency. Safety protocols were rigorously maintained, with no incidents of software collisions or crashes, ensuring that the new CAM programs were safe for use. Additionally, the optimization efforts freed up approximately 684 minutes per month, thereby increasing the machining center's productivity. This research not only demonstrated significant cost and time efficiencies but also provided a scalable model for enhancing quality and safety in manufacturing environments.

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