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USING FCUB FUNCTION IN CNC PROGRAMMING TO MITIGATE FAILURES IN DRILLING PROCESS WITH GUN DRILLS

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Abstract. *The present study aims to enhance the performance in the utilization of gun drills in drilling process, which consistently experience breakages when using standard CNC functions for such processes. During this process the variation of feed parameters is sensitive and crucial for achieving precise, finished results without waste. Given the significant geometric and parameter complexity involved, there arose a need to employ new strategies supported by advanced technologies. Through the aid of a parallel Python program, we were able to significantly improve the outcomes. Throughout the study, tests were conducted replacing the CNC functions FNORM and FLIN with FCUB. The FCUB function utilizes a cubic equation, allowing for smoother machining. Comparative analysis with the assistance of images revealed an improvement in the hole surface finish, both at the entrance of the gun drill and along its entire machined length. All parallel processes to CNC programming, such as drill sharpening and cutting fluid usage, were monitored and parameterized to ensure no interference in the current analysis and consequently minimize disruptions in this research. The optimized process resulted in a 76% reduction in tool breakage rates and a 288% increase in the production of parts using the same tool, tripling its lifespan.*

Keywords: CNC, Programming, FCUB, Gun Drills, Materials, Processes.

1. INTRODUCTION

Drilling of small and deep holes is a challenging task especially in hardened steels. The final quality of a hole depends on the type of tool used and on other factors, such as the rigidity of the machine and clamping device, cutting speed, feed rate, type of lubricating-coolant oil, use of pre-hole or guide bushing in the hole among others. Gun drilling is renowned for its ability to create high-quality, straight holes with varying depths and diameters. This highly efficient process is widely utilized in the automotive industry to drill deep holes in components such as cylinder heads, crankshafts, and fuel pump housings. Additionally, gun drilling finds extensive application in sectors including mold and die, power, and others for drilling a variety of materials. However, it is important to note that the process efficiency, measured in terms of cost per unit length of drilled holes, can vary significantly across different applications. Gun drilling using specialized tools is a valuable technique in machining processes, enabling the creation of precise and high-quality holes. Its broad application in the automotive industry, as well as in mold and die and other sectors, underscores its significance and versatility. Nevertheless, it is crucial to understand that the efficiency of this process depends on a range of factors, including specific application characteristics and involved variables (Astakhov, 2008).

Gun drills are commonly used in machining of precise holes of diesel injector bodies. In general, the materials used in the manufacturing of injection components are low alloy steels from the 41XX family, which are alloyed with chromium (~1%) and molybdenum (~0.2%) and exhibit high strength after heat treatment. The main steels from the family are AISI/SAE 4140, 4144 and 4150, the last two being the most used in the manufacture of injection holders. Chromium-molybdenum machine construction steel 50CrMo4 is equivalent to AISI 4150. Microstructural analysis reveals that 50CrMo4 exhibits a ferritic matrix with carbide inclusions, providing it with strength and hardness. Careful manipulation of the microstructure is crucial to optimize the steel's properties, and studies have focused on investigating heat treatments that can enhance its fatigue resistance, toughness, and performance at high temperatures. Regarding its mechanical properties, 50CrMo4 stands out for its high tensile strength, moderate ductility, and good toughness. These characteristics make it a suitable choice for applications that require strength and structural reliability. It´s a material that can be easily heat treated such as quenching and tempering to optimize the material's properties. These processes allow

for adjusting the hardness, strength, and toughness of 50CrMo4, tailoring it to the specific requirements of different applications. In terms of applications, 50CrMo4 is frequently utilized in transmission components such as gears, shafts, and connecting rods due to its high fatigue strength and ability to withstand high loads. Additionally, the material finds use in structural components of machinery and equipment, where the combination of mechanical strength and toughness is crucial (Wosniak et al., 2010).

Solid cemented carbide gun drill is the primarily choice for deep-hole drilling, and it has been widely employed to machine deep holes in automobiles components (Wang et al., 2011). Gun drill is composed with drill bit, drill pipe and drill handle. The tip part of the drill bit is the cutting edge, and the circumference part is distributed with the guide block with the function of guiding and polishing, which can improve the machining accuracy of the hole. The drill pipe is usually of "V" groove structure, and the chips are discharged through the V-groove under the action of high-pressure cutting fluid (Liang et al. 2022). In order to improve tool performance, several types of coating can be applied. One of them is Balinit Futura Nano. This coating, based on titanium aluminum nitride (TiAlN), is applied using the physical vapor deposition (PVD) technique. The PVD process is employed to deposit thin coating layers on cutting tools. During the process, the coating material is evaporated and condensed onto the surface of the carbide gun drill. This coating is characterized by its multilayer structure, designed to provide an optimal combination of hardness, wear resistance, and low friction coefficient. Its high hardness imparts resistance to abrasive wear, resulting in an extended tool life and enhanced cutting-edge stability. Furthermore, the coating exhibits low surface roughness, contributing to superior surface finish of machined parts. The reduction in friction coefficient provided by the coating enables smoother and more stable machining, reducing heat buildup and the risk of workpiece adhesion to the carbide gun drill. This leads to improved cutting efficiency, lower energy consumption, and reduced tool wear. This coating finds diverse applications in the machining industry. It is frequently employed in the machining of hardened steels, aluminum alloys, and other difficult-to-machine materials. Additionally, it is utilized in situations that require high wear resistance and long tool life, such as in the automotive and aerospace industries. It is important to note that the performance of the coating is directly influenced by machining conditions and cutting parameters. Proper selection of these parameters, such as cutting speed, feed rate, and cooling, is crucial to maximize the benefits of the coating and achieve consistent and high-quality results (Oerlikon Balzers, 2023).

CNC programming plays a fundamental role in the machining industry, enabling precise control of cutting and machine movement operations. To enhance feedrate programming capabilities, the FNORM, FLIN, and FCUB functions have been developed based on the DIN 66025 standard. The FNORM function adheres to the behavior defined by the DIN 66025 standard and is considered the default setting. In this mode, a programmed feedrate value (F) in the CNC block is applied uniformly throughout the block's path and is regarded as a fixed modal value. On the other hand, the FLIN function allows for linear variation of the feedrate (F) throughout the CNC block's path. This means that the programmed F value can gradually increase or decrease from the initial value at the block's beginning to the final value at the block's end. The F value is then considered a modal value. The FCUB function is an advanced option that enables non-modal programming of the feedrate (F) using a spline. The non-modally programmed F values at the block's end are smoothly connected through the spline. The spline starts and ends tangentially to the preceding or following feedrate setting, facilitating smooth transitions and precise control of the feedrate. These functions offer significant benefits in machining complex workpieces. They allow for the programming of continuously smooth speed characteristics that adapt to the workpiece's curvature. This results in the manufacturing of uniform workpiece surfaces, avoiding jerk-free acceleration changes. It is important to note that the FNORM, FLIN, and FCUB functions are widely used in various CNC systems from different manufacturers, providing flexibility and advanced control of the feedrate during machining operations (Siemens, 2023).

The use of gun drills in the drilling process of automobile components is a commonly employed technique in the industry. However, even with the application of CNC functions considered standard, problems such as frequent tool breakages are reported. In this sense, this paper aims to present an approach to improve performance and reduce the breakage of carbide gun drills coated with TiAlN used in the drilling process for fuel passage and admission in the valve chamber area of a diesel injector body. Specifically, we focus on a hole with a diameter of 1.25 mm and a depth of 27 mm. The raw material used for the manufacturing of the component machined with the gun drill, which underwent various tests by changing the CNC programming, was the 50CrMo4 steel. It was observed that this process had a high rate of breakage. Notably, most of the breakages occurred at the beginning of the hole, affecting a specific product. An identified relevant aspect is the importance of proper selection of feed parameters and coolant pressure. Any variation in these parameters can significantly affect tool life and hole quality. Additionally, drill geometry, including helix angle and tip shape, also plays a fundamental role in tool performance.

Given the high cost and frequent breakages in this process, our efforts were focused on reducing the deviations caused by breakages and improving tool performance. Initially, we identified that the tool life was 150 holes, with an average flank wear of 0.10 mm. This resulted in the need for several tool sharpenings, totaling 10 sharpenings per tool and 1500 holes per tool using old CNC programming according to a history of more than 6 months followed by the company's tooling team. To reduce the breakage rate, we reviewed the drilling process, adjusted the coolant pressure, and modified the acceleration ramp of the feed. Previously, the acceleration ramp was a linear transition between the depth coordinates

and the specified feed, represented by the FLIN command for linear feed. We proposed using a feed transition through a cubic function, represented by the FCUB function, which created a spline relative to the trajectory and feed coordinates.

To make the programming clear and objective, we developed a Python program to graphically represent the feed transition. This method allowed for better visualization and understanding of the programming, facilitating the identification of possible improvements. Throughout this paper, we will describe in detail the steps taken, the results obtained, and the improvements achieved through this approach.

2. METHODOLOGY

The methodology adopted in this study to improve performance and reduce drill bit breakages in the drilling process for fuel passage and admission in the valve chamber area of a diesel injector body consisted of the following steps.

Data collection on drill bit breakages: Initially, data on drill bit breakages during the drilling process were collected. These breakages occurred during the machining of a hole with diameter of 1.25 mm and depth of 27 mm (Figure 1) on a 5-axis machining center, Chiron DZ12 model. Using the program with a linear function, historically, a tool breakage every forty-eight hours of production was observed in a total of 43 failures in 3 months. The fractures occurred at the beginning, middle, and end of the drilling process indiscriminately.
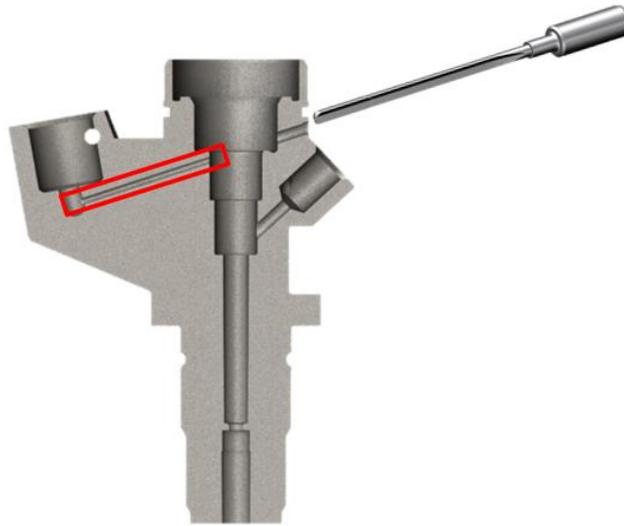

Figure 1. Hole of fuel passage and admission in the valve chamber area of a diesel injector body

Analysis of the relationship between process, machine, and tool: Other applications of the same tool and machine used in the process were analyzed. It was found that the tool did not experience breakages in other products, indicating that the issue was not related to tool sharpening deviations. Furthermore, the machine did not contribute to the breakages as there were no reports of breakages in other products machined by the same machine. It was not possible to measure machining forces due to the lack of precise equipment.

Analysis of drilling parameters in the previous process: A detailed analysis of the machining program and cutting parameters used in the previous drilling process was conducted. The objective was to identify possible areas for improvement and process optimization.

Implementation of drilling process improvements: Based on the previous analysis, improvements were made to the drilling process. The tool approach to the workpiece was reviewed, and the rotation and feed rates used were verified to ensure compliance with the manufacturer's specifications.

Modification of lubricant fluid pressure: adjustment was made to the pressure of the lubricating oil used during the drilling process. The pressure was reduced from 50 bar at the beginning of the hole to 20 bar, and then increased to 135 bar and maintained until the end of the drilling operation. This modification aimed to improve tool lubrication and cooling, reducing friction and wear.

Modification of the feed transition method: A change was made to the feed transition method used during drilling. The linear transition method was replaced with a cubic method, which provided a smoother transition closer to the requested feed range. Python's graphical assistance was used to represent the new feed transition in Figure 2.
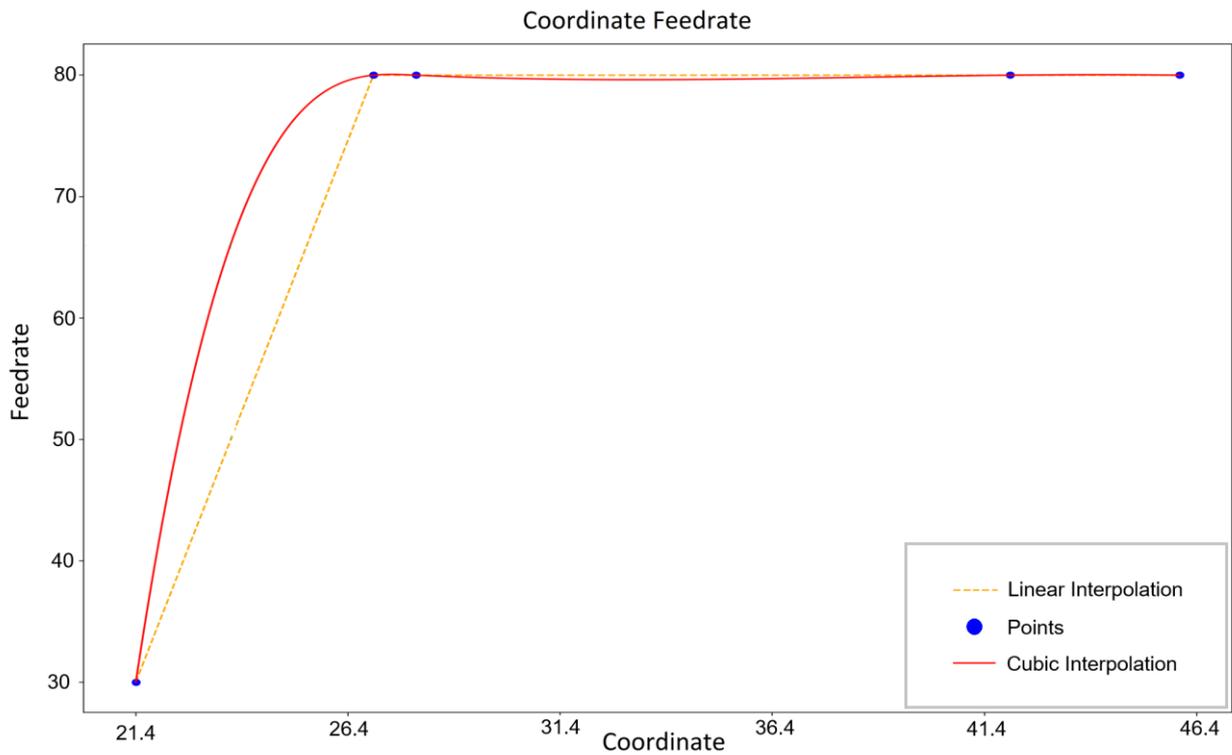
Figure 2. Image of a graph generated by Python.

Indeed, a study was conducted on the feed transition method, replacing the linear method with the cubic method as shown in Figure 3 and Figure 4. The feed continued in a cubic strategy from Fcub Z-21.4 to Z-46, and then it returned in a standard block-to-block (FNORM) to Z-43, constituting a rapid retraction from the bottom of the hole. This change provided a smoother transition closer to the requested feed range, further improving process performance.

```
;processo anterior :
;==============================================================
G1 Z-18.2 F3000 S1000 M3
G1 Z-21.64 F100 H77=50
G1 Z-24.14 S14000 M7 H77=100 F80
G1 FLIN Z-27 H77=100 F90
FNORM
G1 Z-46 S14000 M7 H77=100 F90
G1 Z-8 F5000 S500 H77=20
G0 Z50 M3 S700
;==============================================================
```

Figure 3. CNC programming code used prior to the FCUBE function.

```
;================================================================
;processo proposto (atual) :
;================================================================
G1 Z-19 F3000 S750 M3
G1 Z-21.4 F30 H77=20
S14000 H77=135
FCUB
G1 Z-27 F80
G1 Z-28 F80
G1 Z-42 F80
G1 Z-46 F80
FNORM
G1 Z-43 F3000
M19
G0 Z50 M3 S700
;================================================================
```

Figure 4. CNC programming code using FCUBE.

The results were analyzed in terms of tool wear and breakages.

3. RESULTS

Comparative tests were conducted for comparison between linear feed and cubic feed approaches. The tool using linear feed exhibited a crater wear of 0.127 mm after 150 holes (Figure 5), while the tool using cubic feed showed only 0.04 mm crater wear after the same number of holes (Figure 6).

Figure 5. Tool after 150 drilling operations in old process.

Figure 6. Tool wear after 150 drilling operations in new process.

A long-duration test was carried out, once the drilling process with cubic feed was implemented, and the performance stability over time was verified. It was observed that the tools had less wear, and no breakages were identified during the

stability period. A proposal was made to increase the tool's lifespan from 150 holes to 250 holes. The long-duration tests were repeated, considering a lifespan of 250 holes for the tool using cubic feed. In this case, the observed crater wear was 0.09 mm after 250 holes.

Due to the reduced tool wear, a smaller amount of material removal during the resharpening process was possible. This allowed an increase from 10 to 17 resharpenings in a single tool. While the linear feed process allowed for 1,500 holes before tool replacement, the cubic feed process enabled 4,250 holes before replacement.

It was possible to observe not only reduction of tool wear but also a significant improvement in surface finishing, as well as in the overall machined length. In the tests, we used the same pressure in both scenarios, and the surface finishing exhibited the same trend, Fnorm/Flin showed larger irregularities and Fcube showed a significant improvement in surface finish (Figure 7). The smoothing of the drilling process brought stability and enhanced quality to the entire process in a highly significant manner.
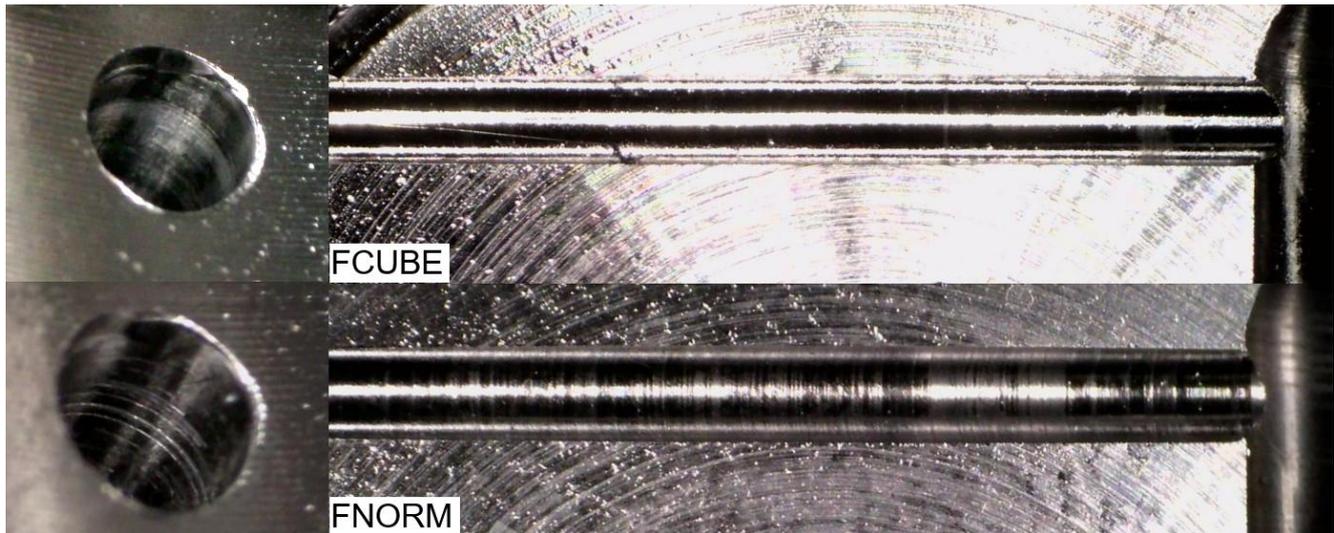

Figure 7. Hole quality obtained by using FNORM and FCUB functions in CNC programming, along with their respective perspective views and cross-sectional representation.

4. CONCLUSIONS

The adopted methodology allowed for a comprehensive analysis of the problem, identifying the main causes of tool breakage and seeking solutions to improve process performance. Initially, data collection on gun drill breakages was conducted, revealing an average of one breakage every two days of production. Subsequently, meticulous analyses were performed on the relationship between the process, the machine, and the tool, verifying that the tool did not have any deviations in sharpening and the machine did not contribute to the breakages.

Modifications were made to the drilling process, such as revising tool approaches and feed rates. Another important modification was the variation of the lubricating fluid pressure, increasing it at the beginning of the hole and maintaining it constant throughout drilling. This change contributed to enhancing tool lubrication and cooling, reducing friction and wear. An innovative approach proposed in this work was the use of a cubic function for feed transition, represented by the FCUB function, as a replacement for the linear FLIN function. This strategy has the potential to smooth the machining process, reducing the occurrence of breakages and improving hole finish. The use of a Python program for feed transition programming allowed for a clear and objective graphical representation, facilitating analysis and identification of possible enhancements.

The results obtained so far indicate a significant reduction in the breakage rate of gun drills, as well as an increase in tool life when FCUBE was used instead of FNORM/FLIN. Furthermore, an improvement in hole surface finish was observed. We conducted the test with the same lubricating fluid pressure in both scenarios, and the surface finishing in both cases matched what was reported. These advancements are of great relevance to the industry as they contribute to cost reduction and increased efficiency of the drilling process.

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE