Final Report Submission

To

Oregon Manufacturing Innovation Center, Research and Development (OMIC R&D)

CGTech Force MillTurn Optimization (OMP411)

February 2020

Joshua Koch

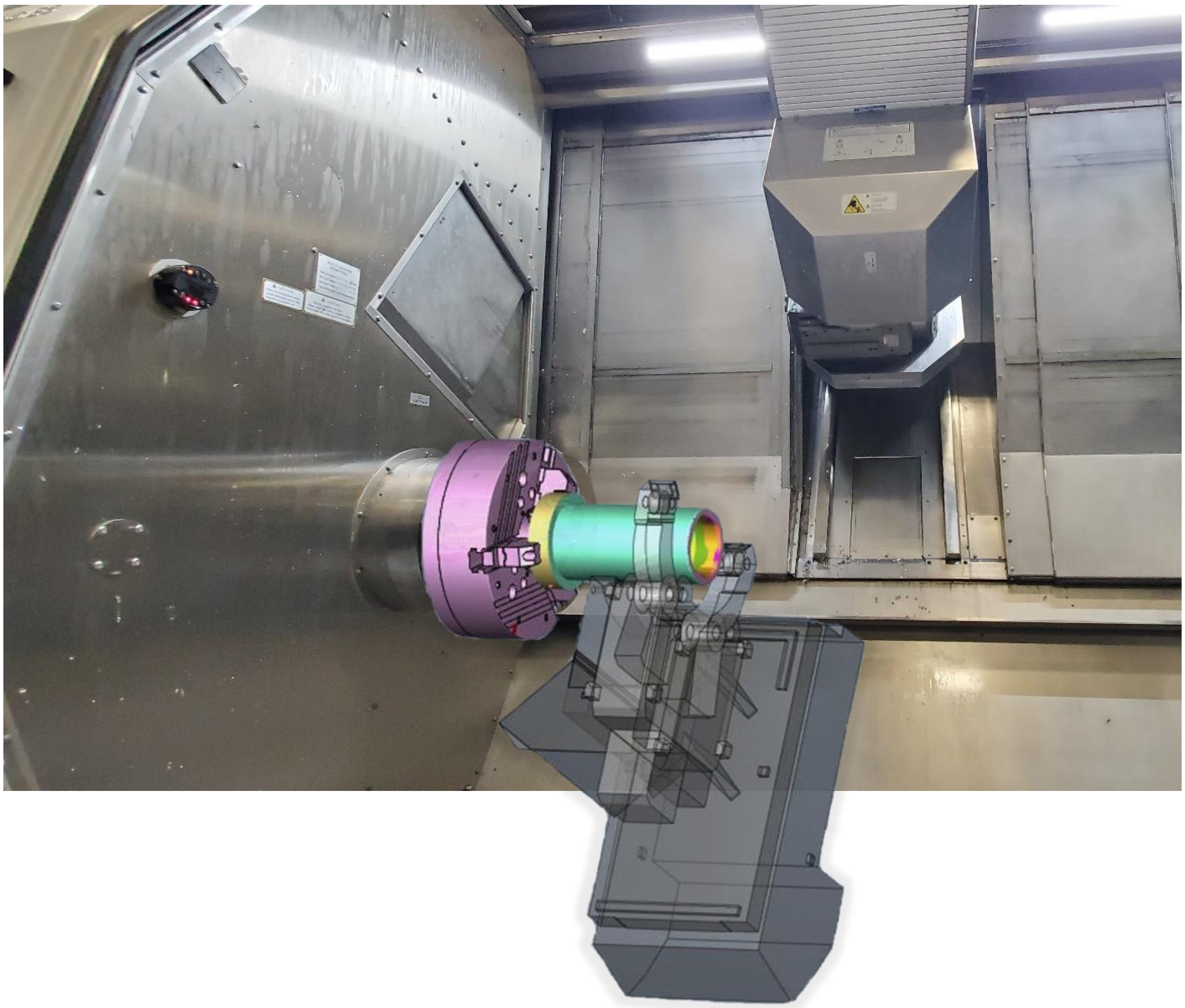
Principal Investigator

Josh.Koch@OIT.edu

OMIC

CGTech VERICUT: Review of Force Module

February 2020 – Product Review White Paper



WFL MILLTURN TECHNOLOGIES

CCTECH

WALTER

OMIC R&D

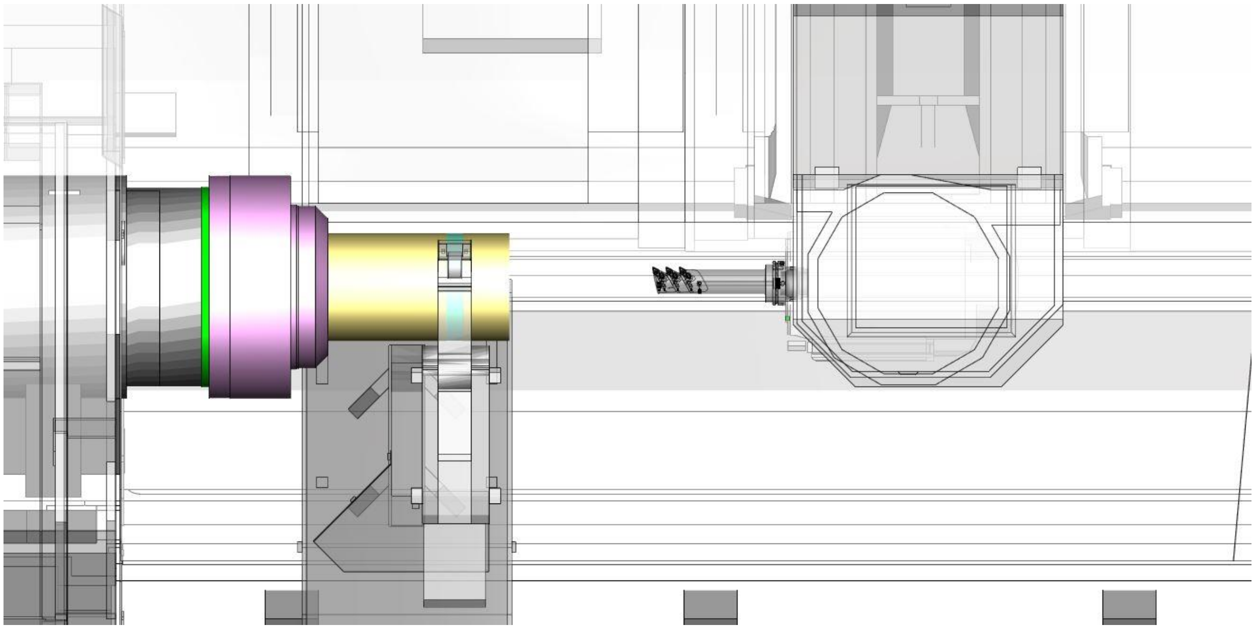
KENNAMETAL

IMS SOFTWARE

TABLE OF CONTENTS

1.0 FOREWORD

OMIC R&D is a collaborative research and development center specializing in direct implementation of Research for the manufacturing sector. OMIC R&D has prepared the following white paper as a review of CGTech's VERICUT Force module. CGTech is a member of the OMIC R&D collaborative center in Scappoose, Oregon. CGTech provides OMIC with licenses of all CGTech products for NC verification of its equipment, CGTech also provides training and resources to ensure OMIC R&D staff are trained and competent users of their software. The author of this white paper has used CGTech products for 5 years. The author's intent is to provide an unbiased assessment of the technology based on data and experience, the opinions expressed below are the authors and may not necessarily reflect the opinions of CGTech.



2.0 INTRODUCTION

This project was designed to offer an unbiased review and evaluation of VERICUT Force for OMIC R&D members from an experienced user of the principal software. The project was designed to look at how Force could improve productivity and reduce costs for parts in MillTurn applications, this specific application was chosen as it overlaps three major machining sectors: Turning, Milling, and Mill Turning (Polar Milling). To test the software, we created a facsimile component based on an Aerospace component programmed previously. The part was evaluated then optimized, demonstrating a calculated cycle time reduction of 17% on a facsimile of a previously optimized production component. It is the recommendation that VERICUT Force can reduce cycle times and avoid premature tool wear / chipping after an NC program has been proven out. To run it prior to machining a programmer would need historical cutting data and standardized material removal methodologies.

2.1 Company Background

CGTech is a software company specializing in NC / CNC machining simulations. Headquartered in Irvine California and founded in 1988 CGTech has created several simulation modules all based off their principal product, VERICUT. CGTech has offices in 13 countries across 4 continents, they have also partnered with many companies and colleges to host training and events across the United States.

2.2 VERICUT Background

VERICUT has been helping users save time, money, and build confidence by proving out NC code eliminating machine crashes and scrapping of parts. VERICUT takes into consideration all aspects of the machining process to create a digital twin of the manufacturing process. The machine model, tool models, part models, stock models, kinematics, and NC program are all replicated digitally and simulated to give the programmer the confidence that their programs will work right the first time. VERICUT has created several Modules over the years to enhance verification of machining and keep pace with new additions to the manufacturing space. This includes verification of composite manufacturing & machining, additive manufacturing, robotic integration, probing, and "AUTO-DIFF" which allows comparison of the finished part to the virtually machined one.

2.3 Force Background

VERICUT filled a crucial role in the manufacturing sector as it could test for machine collisions, fast feed conditions and other common manufacturing problems. However, there was no way to verify that cutting tools were being used optimally to reduce program time and increase cutter life. Force was introduced to solve this problem. By knowing tool and material characteristics calculations of the contact between the tool and material are done to evaluate and optimize Maximum Chip Thickness, keeping it constant while providing a safer NC program by limiting Total Force.

2.4 Definitions

Average Chip Thickness: The calculated thickness of the unformed chip at a right angle to the cutting edge. Feedrate, engagement, edge preparation, and lead angle all play crucial factors in the calculation.

Maximum Chip Thickness: Like Average Chip Thickness but calculated from area of highest material removal.

Total Force: The combination of *Tangential Force* which overcome the resistance to rotation, accounting for 70% of total force. *Feed Force* which is the resistance to progression, accounting for 20% of total force. Finally, *Radial Force* which tends to push the tool away, accounting for 10% of total cutting forces.

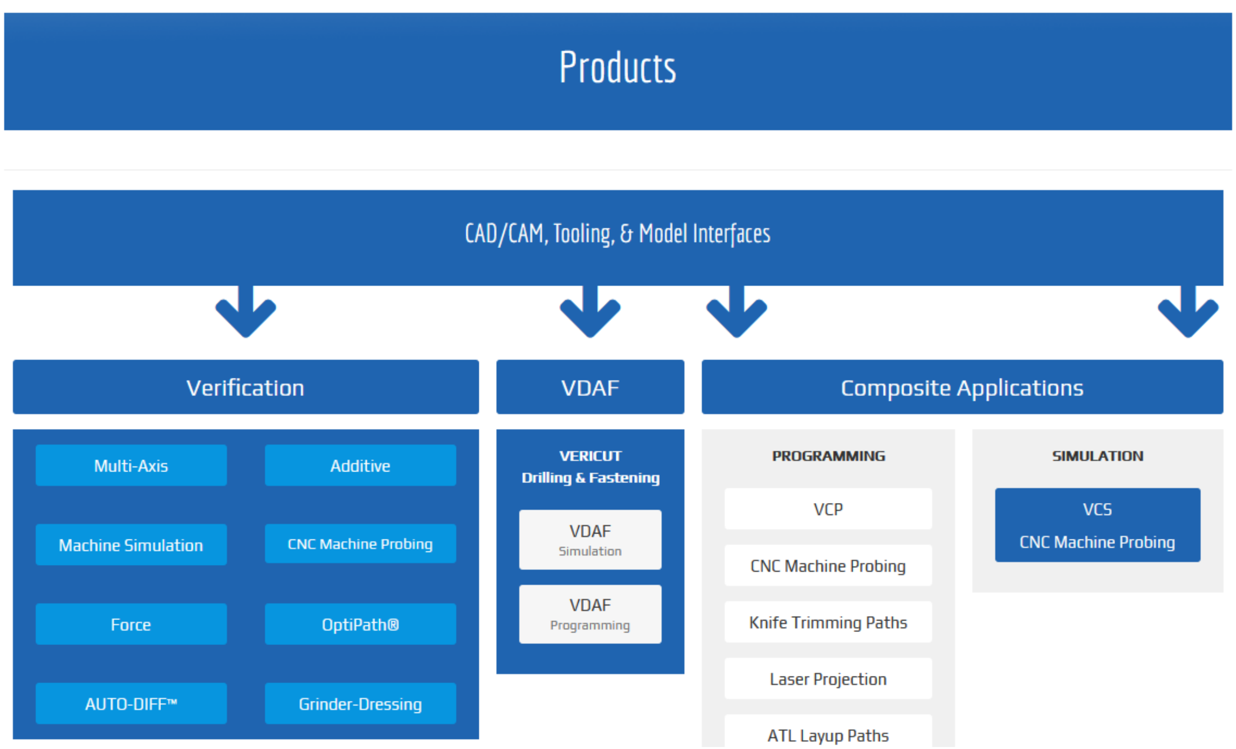
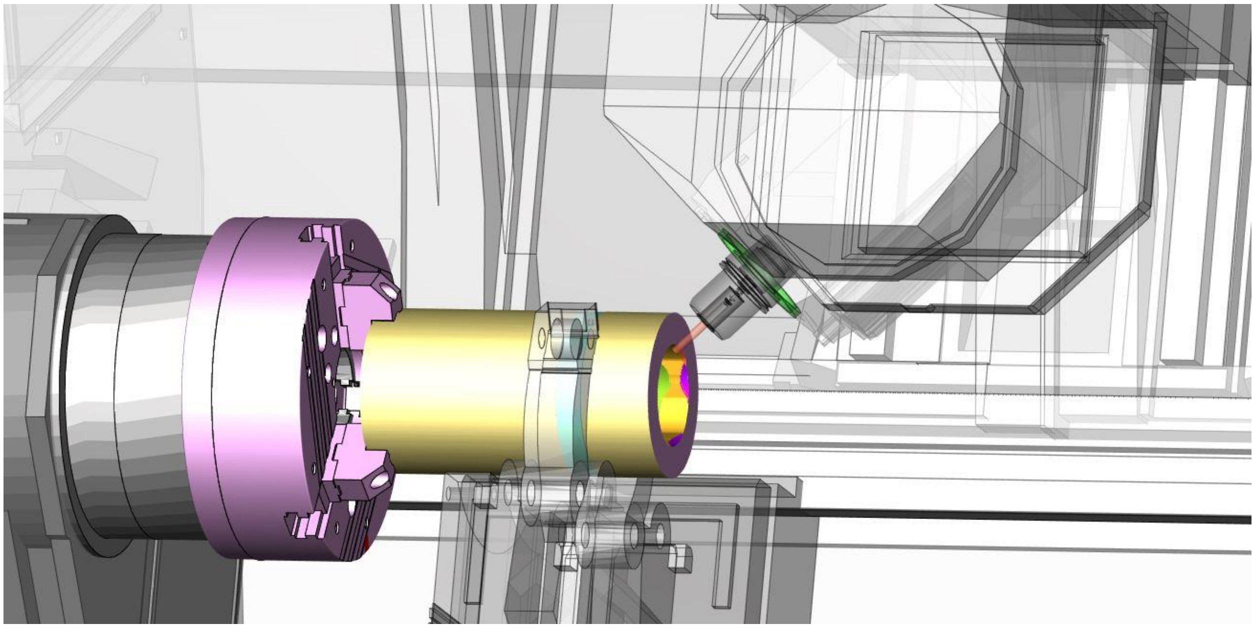


Figure 1 - CGTech overview of product offerings



3.0 METHODOLOGY

3.1 Project Preparation

In collaboration with CGTech the first task of this project was to create a facsimile component based on a Boeing component that the author programmed for production on a WFL M80. Dimensions were standardized and non-machined features were removed. The tool path was then reconnected in CATIA V5 (the original CAD/CAM software) and was output. The same IMS post processor was used that generated the code for the original production part. OMIC then reached out to the cutting tool manufacturers for the same tool model files used in the production program. The goal was to duplicate as closely as possible the original VERICUT Project File they had created at Boeing.

3.2 VERICUT Force Inputs

VERICUT requires only a couple of inputs to analyze forces, the first is a material file and the second is cutting tool information. CGTech calibrates material files with their FORCE Calibration software and dynamometer setup. The material files are generated by taking a standardized assortment of cuts using a Kistler dynamometer on a specified material at a designated hardness to collect the force data. The Force module comes loaded with Ti6AL4V at HRC36 and 6061-T6 Aluminum at HRB53. Any other material files either need to be obtained from CGTech's library of materials or created with VERICUT FORCE Calibration. The other input is cutting tool information. Since cutting tool information is already partially loaded for simulation purposes, there are only a few additional pieces of information required. For Milling you need to know Helix Angle, Radial Rake Angle, Cutter Material, and Edge Type. If the cutter is indexable, it will also need to know the Insert Rake Angle. For Turning you need to know the Insert Rake Angle and the Cutter Material.

3.3 Analyzing vs Optimizing

Inside the Force Module there are two major options. The first is for Analyzing and the second is Optimizing. Analyzing is done first and the results and paired with programmer experience allowing you to create optimization parameters. Optimizing will then use those parameters to increase feed / speed of tools to make chip thickness more consistent and/or reduce spikes in cutting forces to reduce the potential for chipping or premature tool wear. VERICUT will look at NC motion and split up G01, G02, and G03 motion into segments within the original start and end points of any line of code. These segments will then have adjusted feeds and speeds to control Chip Thickness or Total Force.

3.4 Analysis Results

While watching the analysis it quickly becomes apparent how much fluctuation there is in a machining process that may have been assumed as just a consistent 2D linear cut (Figure 2). There are many charts and graphs available to you including Chip Thickness, Total Force, Radial/Axial Force, Machine Force, Torque, Power, Removal Rate, Deflection, Speeds, and Feeds. At the very least, Minimum Chip Thickness and Total Force are needed as this information is used when setting up the tools for the Optimization. In the below graphic, many variables are monitored during the replay.

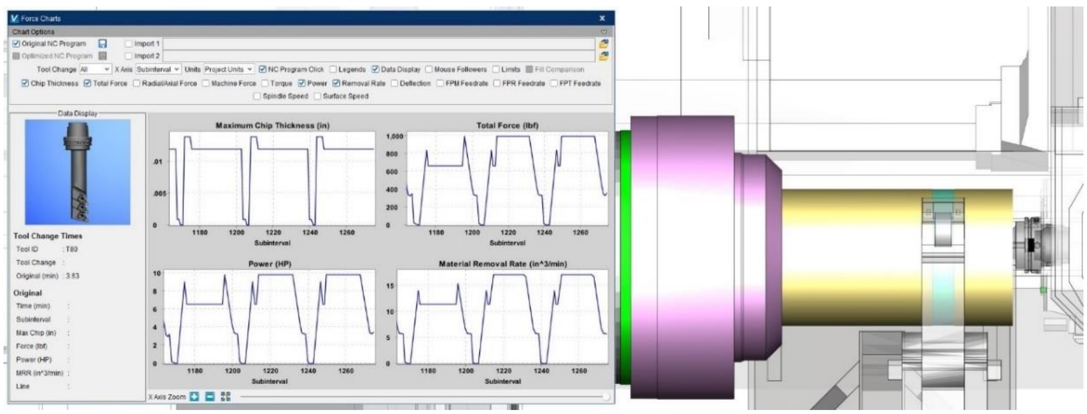


Figure 2 - Analysis of cutting forces for an ID Tiger Claw

Once the verification is completed, the Force Charts window can be set to a specific tool and the Tool Manager window can be opened (Figure 3). To Optimize, Optimization method needs to be selected. The method most widely used for Milling and Turning is, Chip Thickness & Force. The Default options are a good start to this process. However Maximum Cut Feedrate, Air Cut Feedrate and Clean-up Feed rate need to be set. These can typically be well above programmed feed rates because under Optimization Settings the limiters of Chip Thickness and Force are set. Having experience machining this component, a Chip Thickness at the upper limit and a Force Limit just under peak were safe choices for this tool.

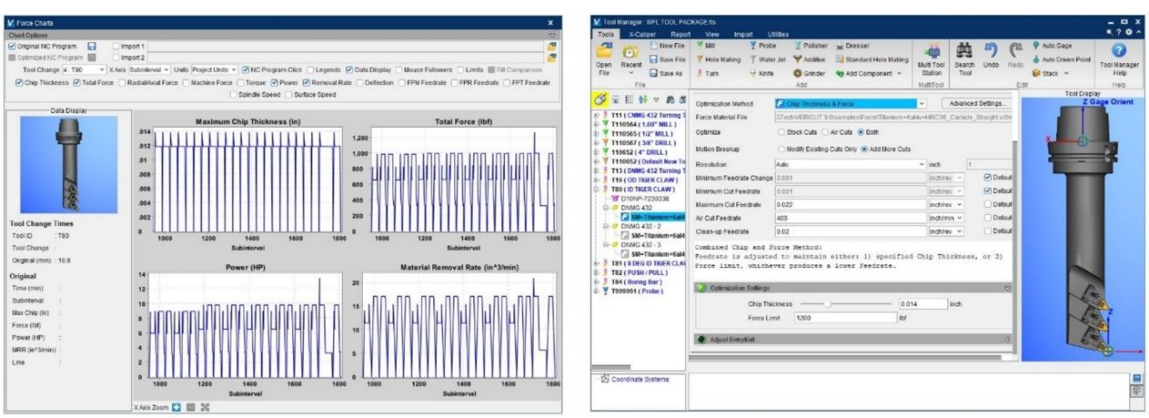


Figure 3 - Using Analysis data to create a tool optimization file

3.5 Optimization Results

After the tools have been given some default and initial parameters, the simulation is run again in Optimize mode (Figure 4). In this mode three things happen as shown in Figure 2, the blue analysis graphs of the original program are regenerated, a red optimized graph is generated, and a new NC file is generated with the ability to save it and use it for machining. In the below graph of the same tool that was analyzed above, the Maximum Chip Thickness increased because of an increase in feed rate. Here the Chip Thickness was the primary limiter (Total force is about 100lb less than the 1200lb limit), however in the Total Force chart when it tried to spike above the preset tool's Max Force the feed rate was reduced and consequently there is a dip in Chip Thickness.

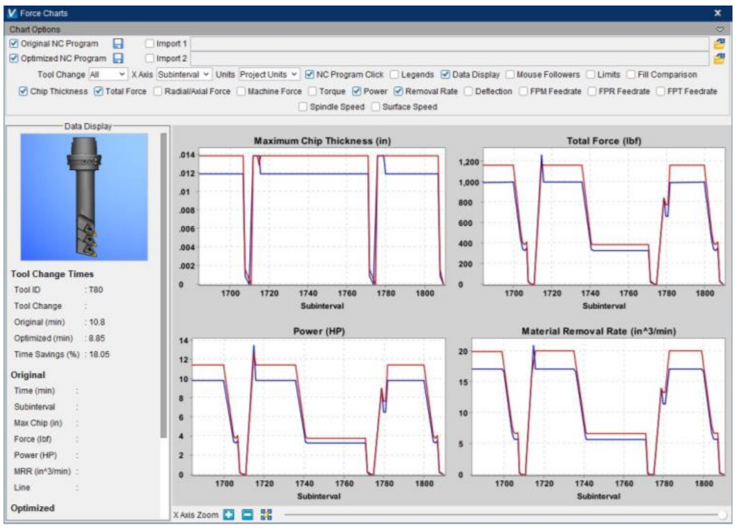


Figure 4 - Optimization results in red for ID Tiger Claw

Below is a good example of potential tool life savings by controlling chip thickness. The test component had an internal bottle bore with steps left over from the previous machining operation (Figure 5). Feed rate was increased to create consistent Maximum Chip Thickness, so the insert did not cycle between load and no load causing the potential for chipping.

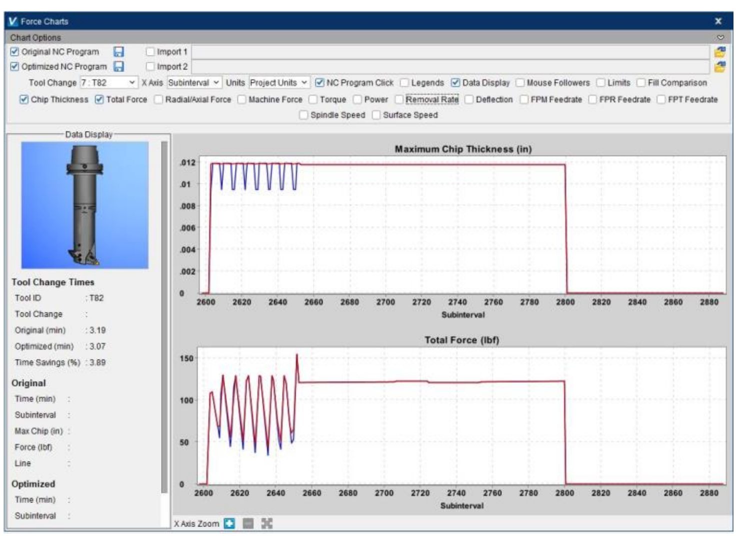


Figure 5 - Optimization results in red for ID Boring Bar

On a multi-axis machining cut it can be difficult to create consistent machining paths during all phases of the cut including the lead-in, the machining, and the lead-out (Figure 6). With Optimization running not only did it limit spikes above the chip thickness the programmer specified, it also reduced several small fluctuations within the cut which could potentially increase tool life and improve surface finish. There were also several sections that were sped up, decreasing overall run time.

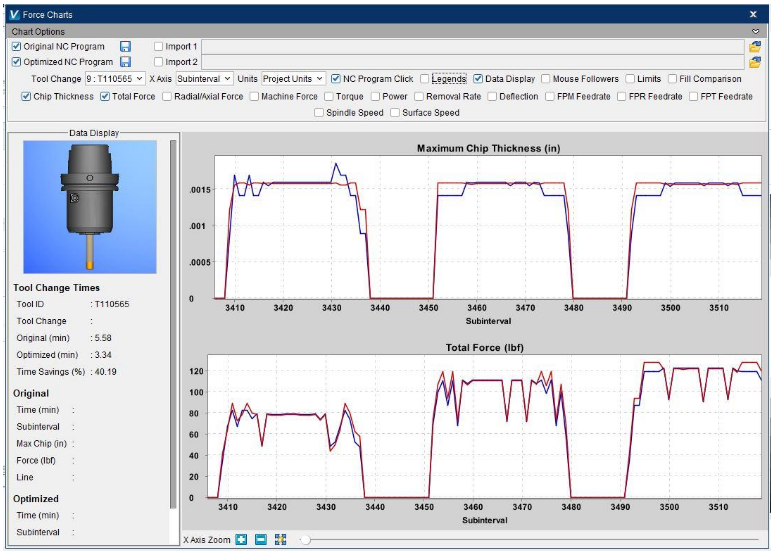


Figure 6 - Optimization results in red for 1/2" Endmill

3.6 Cycle Time Reduction

The part used for this White Paper has 4 programs (2 roughing and 2 finishing). On just the first program a greater than 17%-time savings was noted (Figure 7). This percentage was higher than what thought was achievable, since this part had been optimized over several production runs. Several of the tool paths had been hand drawn to further reduce cycle time.

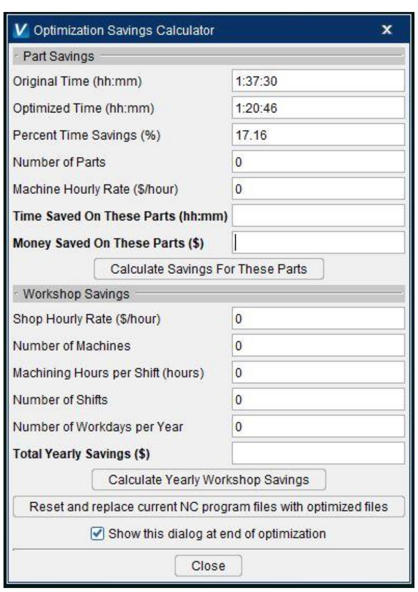


Figure 7 - Cycle time reduction calculator

4.0 KEY FINDINGS

In the below findings it was the goal to not to duplicate information readily available about VERICUT Force, instead the below findings are things that were discovered or really stood out while optimizing an NC program. As with anything, based on the complexity of the tasks trying to be accomplished, limitations or inconveniences arise, in the findings below these along with all the positives during the optimization of a MillTurn component are mentioned.

VERICUT Force is a very comprehensive software allowing users to adjust for many parameters outside of default values and suggested inputs for fields based on running the Analysis tool. You can adjust entry/exit, plunges/retracts, ramp feed/angle additionally you can adjust for material and channel cutting. Cuts can be modified to segment original motion with new commands, or the original individual lines can be modified with new feeds / speeds. A great deal of work was put into the system to make it intuitive, and the basic training for the module was only 4 hours with an additional couple hours of practice. Below are some of my key findings including, predictions of tool life increase, shorter time to optimization for production, and improvements that would be nice to see in future releases of the software.

4.1 Key Findings #1

Chipping is typically caused by excessive loads and shock during machining operations (Figure 8). Chipping can also occur as a result of thermal cracking when loads or shocks are encountered. VERICUT force works to eliminate these shocks during machining operation by adjusting feeds and speeds to create consistent chip load. In the below example of a cut with a boring bar, the DNMG 432 insert, in blue (original NC), had shocks as it was cleaning up a stepped surface from a roughing operation. The adjusted program, in red, removed these shocks creating a consistent chip thickness. To the extent this increases tool life would be valuable cost savings information to add to an already reduced cycle time.

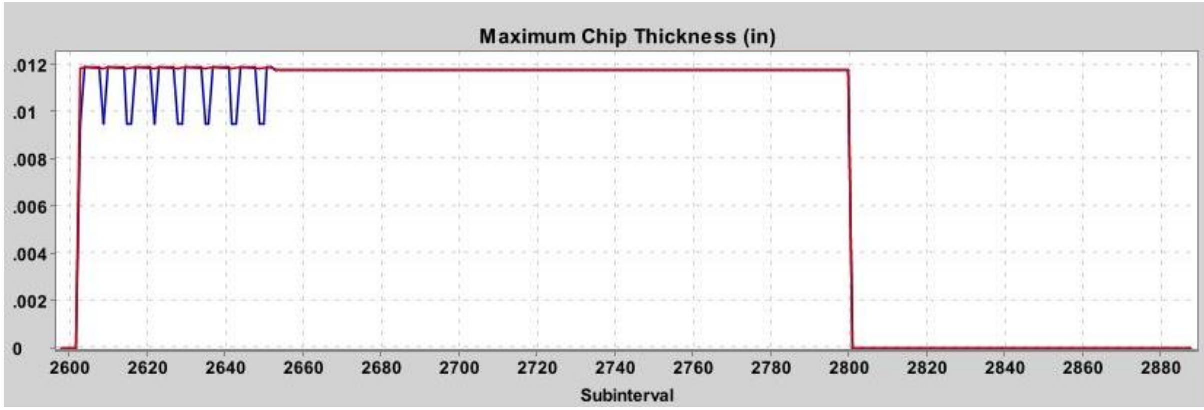


Figure 8 - Optimized tool path in red for an ID Boring Bar, the shock of the tool from the original code has been eliminated

4.2 Key Findings #2

When this program was originally optimized for production it took approximately 10 hours of work. This comprised time watching the part run on the machine and then making corrections in the CAD/CAM file. Everything was adjusted once the program was good including decreasing lead-ins and lead-outs, faster transitions, and increasing feed rates. Using VERICUT Force the time to create an optimized program was greatly reduced to approximately an hour. This represents a huge time savings to the programmer who could move onto other tasks. The quality of the optimization is also vastly improved, in the sense that for a programmer increasing feeds and speeds once they hear the tool make a sound outside their comfort level typically the sequence is capped. However, with VERICUT Force peaks in cutting forces are capped while the remainder of the process can be brought up by reducing cycle time while preserving tool life. In the below graph the blue is the original, and the red is the optimized (Figure 9). Peaks over 0.0016” chip load have been eliminated, while increasing chip load in the valleys to create a more consistent cut.

Figure 9 - Optimization of a 1/2" Endmill in red, the shock of the tool from the original code has been eliminated

4.3 Key Findings #3

Since the software has been well thought out there are only a few minor limitations or improvements that could be done to make the process easier for users. These identified as:

1. Option to assign optimization per sequence within the cutting tool optimization window (Figure 10). Currently, if you want to use the same tool for different applications within the same program, a code needs to be added to the original NC code to call an alternate optimization file for the cutting tool. If switching could be added as an option within this window and could also be added to the modified NC, a programmer could use the same tool for both roughing and finishing in the same program without having to open and modify the original NC code to make the simulation and optimization work.

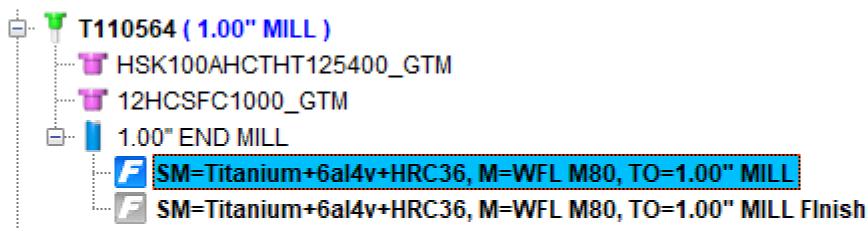


Figure 10 - Optimization Files can be called using an NC code so a tool can have more than one set of parameters

2. A minor inconvenience is found when running the Analysis or Optimization multiple times, each time VERICUT is reset the option needs to be chosen again (Figure 11). Resetting in VERICUT will set the Optimize Control mode option to “off”. Having Force stay enabled once turned on would make it easier to go through repetitive revisions.

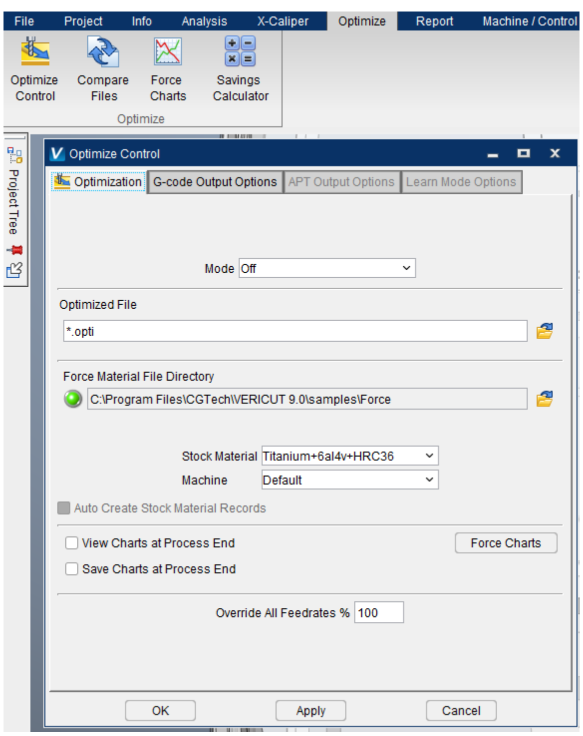


Figure 11 - Optimize Cutting window, for turning on and off VERICUT Force Module

3. An interesting find while doing this project is that Force can only support 1 active optimization file at a time, which means that for turning cutters with greater than 1 insert such as Tiger Claw tools from Walter Tools only the first insert is evaluated (Figure 12). It would be nice if multi-contact tools such as these could be evaluated in the software, but that might mean more stacked charts which could make the results difficult to interpret.

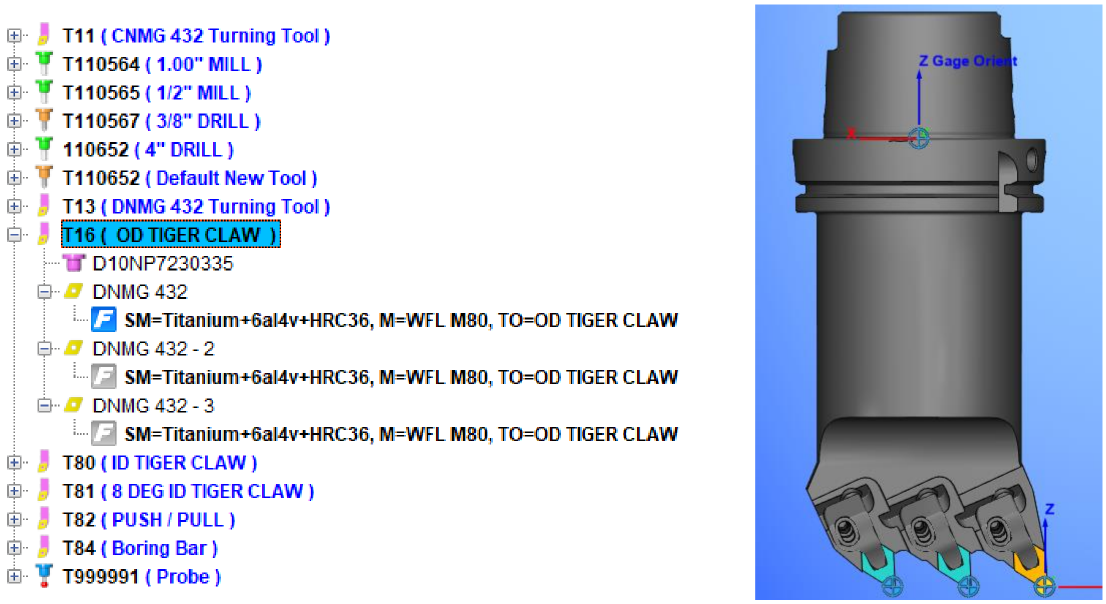
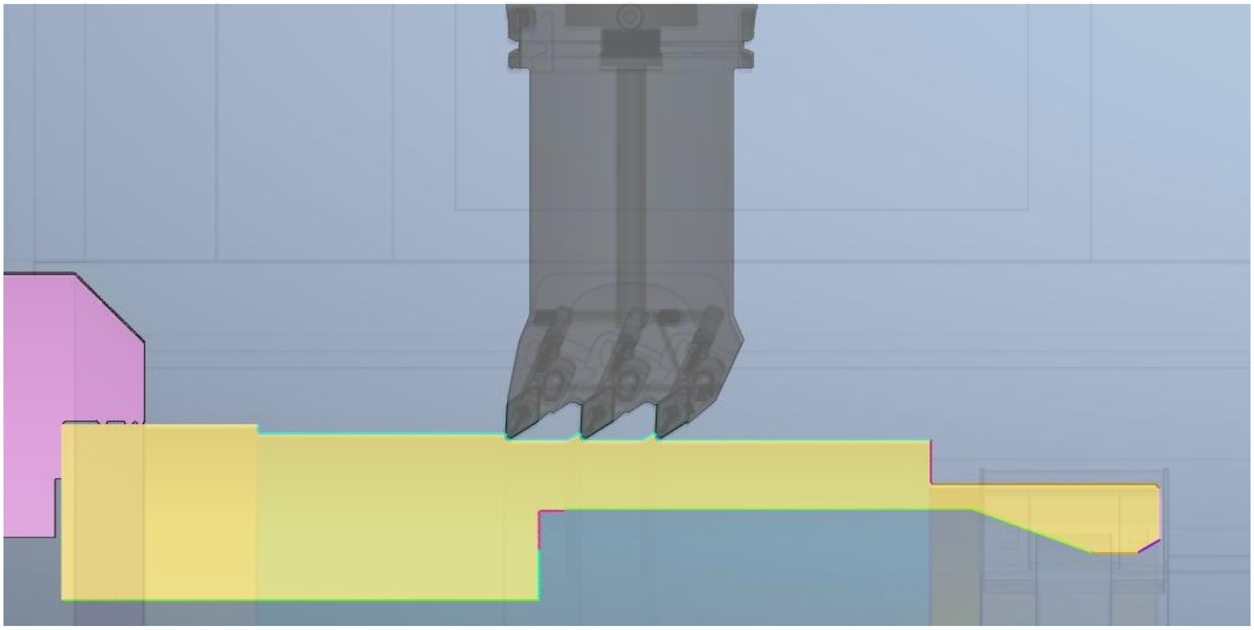


Figure 12 - Only one Optimization File can be active at a time. No data will be logged for the other 2 inserts



5.0 CONCLUSION

To test how well VERICUT Force worked, a part that had already been highly optimized was chosen to prove that even production programs can benefit from Force Optimization with a relatively small investment in time, this was done intentionally knowing that the time savings would not be as great as a program that had used standardized canned routines

5.1 Key Takeaways

1. VERICUT Force has been designed for production shops to reduce runtimes with no major NC re-programming. This allows shops that need to reduce costs or reduce cycle time to meet greater demand to do so without a huge investment cost. A single programmer can make an almost perfectly optimized program given a good production program in a single attempt. In this way, the software is perfect for medium to large shops with production components they make to help reduce costs to stay competitive.

2. VERICUT force can eliminate shocks in cutting forces which is the main reason cutting tools experience chipping. Because the catalyst for chipping has been removed, extended and more consistent tool life is the expected outcome.

   OMIC has yet to cut a VERICUT Force optimized part but expects extended tool life given the feedback from other companies, John Giraldo (Sandvik) working with CGTech as Okuma partners in Thinc said, *"Using a trochoidal toolpath [i.e., a more efficient way to mill a slot or pocket by using circular movements with lighter radial engagement at higher feedrates] to machine a deep pocket in a cylindrical casing, they were burning up two end mills per pocket," he said. "With Force optimization, we increased tool life to five pockets per tool—a tenfold improvement—and reduced cycle time by 25% to boot. It made a night and day difference."*

6.0 REFERENCES

CGTech. (2020, 01). *Products*. Retrieved from CGTech Website: https://www.cgtech.com/products/product-line.html

CGTech. (2020, 01). *Products: Force*. Retrieved from CGTech Website: https://www.cgtech.com/products/product-line/92-force.html

CGTech. (n.d.). *Okuma/Sandvik: Partners in Force*. Retrieved from CGTech website: https://www.cgtech.com/component/k2/item/358-okuma-sandvik.html#prettyPhoto

CIMdata. (2019). *CGTech VERICUT: A Product Review.* Ann Arbor: CIMdata.

McDonald, M. (2019, 12). Technical Support Engineer. (J. Koch, Interviewer)