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Improving Milling Performance on New Computer Numerical Control Machining Centers with Machining Dynamics

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OAK RIDGE NATIONAL LABORATORY
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Manufacturing Science Division
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This CRADA NFE-19-07915 was conducted as a Technical Collaboration project within the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) sponsored by the US Department of Energy Advanced Manufacturing Office (CPS Agreement Number 24761). Opportunities for MDF technical collaborations are listed in the announcement “Manufacturing Demonstration Facility Technology Collaborations for US Manufacturers in Advanced Manufacturing and Materials Technologies” posted at http://web.ornl.gov/sci/manufacturing/docs/FBO-ORNL-MDF-2013-2.pdf. The goal of technical collaborations is to engage industry partners to participate in short-term, collaborative projects within the Manufacturing Demonstration Facility (MDF) to assess applicability and of new energy efficient manufacturing technologies. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

ABSTRACT

This project is directed at improving the efficiency and productivity of the existing installed US machine tool base by correcting a fundamental system-wide flaw in the existing programmable machine tool infrastructure. The project will catalyze a shift from a geometry-only mindset to a geometry -and-machine -performance mindset. The project will lead to a dramatic overhaul of the existing ecosystem for programming of Computer Numerically Controlled (CNC) machine tools, and will result in energy savings, cost savings, reduced scrap, and improved competitiveness of US manufacturers.

1. PROJECT TITLE

This phase 1 technical collaboration project (MDF-TC-2019-173) began on December 6, 2019 and concluded on March 1, 2020. Phase 2 technical collaboration began in March 2020 and concluded in December 2021.The collaboration partner MSC Industrial Supply Co., Inc. is a large distributor of metalworking supplies to industrial customers throughout the US. The results show that the average increase in material removal rate is 159% for the US manufacturers related to this project.

1.1 BACKGROUND

Currently, and since the beginning of the CNC machine tool era, the CNC ecosystem has had a geometry-only mindset. The tool is considered as a rigid cylinder, and the workpiece is considered as a rigid prism. When programming tool motions, the programmer (with the aid of computer software) chooses a tool path. The software makes Boolean subtractions of all the intersection volumes between the tool and workpiece to create the ideal finished part. However, the tool is not a cylinder – it is a collection of cutting edges bound together and rotating. Neither the tool nor the workpiece is rigid. They can both deflect and vibrate in response to the cutting forces.

With the geometry-only mindset, the length of the tool does not matter, as long as it can reach all of the features of the part. That strategy might work if the tool and the workpiece were infinitely rigid, but they are not. Longer tools are generally more flexible and more prone to vibration and deflection problems during machining. In the current state of the art, the programmer does not even need to know which machine will produce the finished part, since the NC code will later be "post-processed" to create the machine specific code. Clearly this can't work reliably, since each machine is different. The have different stiffnesses, powers, torques, accelerations, and more.

Impact-testing technology allows machine tool users to measure the stiffness and structural dynamics of their specific machining system(machine-toolholder-tool). By measuring the structural dynamics, or tool point dynamics, of their specific machining system, the NC programmer can choose optimal machining parameters that will maximize material removal rate, reduce scrap, and decrease lead times. Impact-testing each tool at the delivery of the new machines will cut the time of getting it into production from months to days. When deployed nationwide, impact-testing's minimizing of the initial setup coupled with its improvement of productivity and increased capacity will save billions of kilowatt-hours of energy each year.

This project proposal leverages America's largest cutting tool supplier, MSC. For this project, MSC is the ideal partner. They have the technical capacity to learn to make the required measurements. They interact directly with almost all of the tens of thousands of machine shops that can benefit from the technology. They sell tools and holders from most every manufacturer and are regarded as an honest broker whose goal is to improve productivity of the machine tool users. Their offices are naturally and neatly aligned with US machine tool distributor locations, so the ability to rapidly improve the performance of newly delivered machines is high.

1.2 TECHNICAL RESULTS

ORNL MDF and MSC successfully completed all of the Phase I tasks. All of the required equipment has been acquired and deployed to ten trained users in separate regional areas. Each of the ten trained users are using the SpeedCast tap-testing kits to improve the milling efficiency of their customers.

Two training sessions were held, one in January 2020 and one in February 2020. The trainees were introduced to the impact-testing technology as well as its application to tool point dynamics. Demonstration videos were presented to the trainees to help illustrate the benefits of the impact-testing technology. The videos were well received by the trainees who were very impressed at the impact that spindle speed can have on milling stability.

The trainees were then introduced to the software interface. The trainees learned how to open the software, connect all of the sensors and hardware, and complete a measurement. A table-top demonstration tool was used to introduce the trainees to the mechanics of hitting a tool with the instrumented modal hammer.

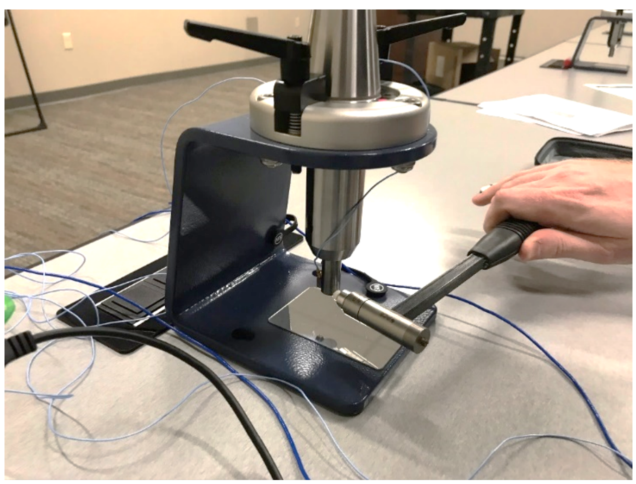

Figure 1. Trainee learning to make a measurement with the table-top demonstration tool

The trainees practiced taking measurements on various tool/tool holder combinations as well as two, three, and four flute endmills. The attachment method of the sensors is different for tools with different flute counts. Each different tool allowed the trainees to become familiar with making measurements on different endmills.

Figure 2. Trainee practicing a tool point measurement on a machine tool

Figure 3. Trainee practicing a tool point measurement on a machine tool

After making measurements on various tools, actual milling tests were performed. Machining parameters were selected using tool vender recommend parameters and also SpeedCast (the impact-testing equipment) recommended parameters. The SpeedCast parameters were better than the tool vendor recommendations from a milling stability point of view as well as material removal rate. Trainees reported that the SpeedCast tool gave them the confidence to push the tool/machine past what they would normally deem "good parameters". One of the tools broke when using the tool manufacturer's recommended parameters. SpeedCast predictions were consistently useful, and some trainees reported that the tool could actually remove more material than the SpeedCast prediction. SpeedCast predictions try and account for milling uncertainties, so conservative predictions are desirable.

Trainees were excited about the SpeedCast technology. They were all able to successfully make tool point measurements. They were excited to go to their customer sites and introduce the SpeedCast technology to them. They were also excited when they were able to make good measurements.

Figure 4. Trainees congratulating each other after a successful measurement

The impact-testing training lasted two days. On the second day, trainees performed measurements again to ensure that the previous day's training was absorbed. Table-top measurements were very useful because each trainee could be next to other trainees who could help.

Figure 5. Trainees using the table-top demonstration tool on the second day of training

The trainees also learned how to use the Harmonizer software on the second day of training. Harmonizer is a supplementary software/technology to the impact-testing technology. Trainees were taught about the differences between the two technologies, and when it is appropriate to use which technology. Trainees were also taught about the advantages and disadvantages of each technology. Trainees liked how easy the Harmonizer software was to use. They also liked that the Harmonizer software did not require extensive setup time or equipment. They appreciated how easy the tool was to use.

Figure 6. Trainees learning to use the Harmonizer technology

Overall, the training was well received, and the trainees reported that the training didn't seem like a long and painful exercise. Trainees were engaged and enthusiastic about learning and implementing this technology.

Figure 7. Group 1 photo from the January 2020 training

Figure 8. Group 2 photo from the February 2020 training

ORNL MDF and MSC successfully completed all the Phase II tasks. Participants were able to use all the online training resources to improve milling productivity on existing and new machine tools in the

United States.

1.3 IMPACTS

The advanced technology innovation is the direct use of tool point dynamics in machining parameter selection at the process planning stage. While it is understood in the laboratory setting that this enables increases in material removal rates (a 2× improvement is typical), implementation on the shop floor is limited. By enabling data collection by MSC, the primary impediment is removed, and US machining productivity can be increased. This project seeks to demonstrate the advantage of impact-testing through multiple use cases and, ultimately, to change the culture of tooling selection from ad hoc or geometry-based to a performance-based model. Laboratory and limited industrial studies have indicated that this change can improve productivity by more than a factor of 2 and maybe as much as a factor of 10, increasing US manufacturing competitiveness. In addition, eliminating the current trial and error process for tooling selection and machine programming will create dramatic savings in machine time, workpiece materials, and tooling. The collected data can be used to provide more accurate cost estimations for new parts, increasing the efficiency of the procurement process.

1.3.1 SUBJECT INVENTIONS

There are no subject inventions associated with this CRADA.

1.4 CONCLUSIONS

The MSC metalworking specialists have already successfully used this technology to improve their customer's productivity. Each time a metalworking specialist improves a customer's process, a report detailing the success is generated. Many technical details of the improvement case are reported, but the most important pieces of information are the annual cost savings and the increase in material removal rate.

MSC metalworking specialists have improved their customers' processes which will result in a total annual savings of $4.5 million, and an average annual savings per milling operation optimization of $10,600. The average increase in material removal rate was 282%. So far, 88 metropolitan areas have seen improvements using this technology with more than 423 different operations that were optimized. The average annual recuperated machine time per customer was 99 hours with a total savings of 42,000 hours across 88 different companies. These results were achieved by impact-testing individual milling tools and selecting more optimum milling conditions. These improvements affected the medical, aerospace, and automotive industries.

Figure 9 shows where all the MSC metalworking specialists are located, and sites with trained specialists are marked in yellow. The next step in advancing this technology is to continue training the MSC metalworking specialists so that every location in Figure 9 has specialists trained in impact-testing.

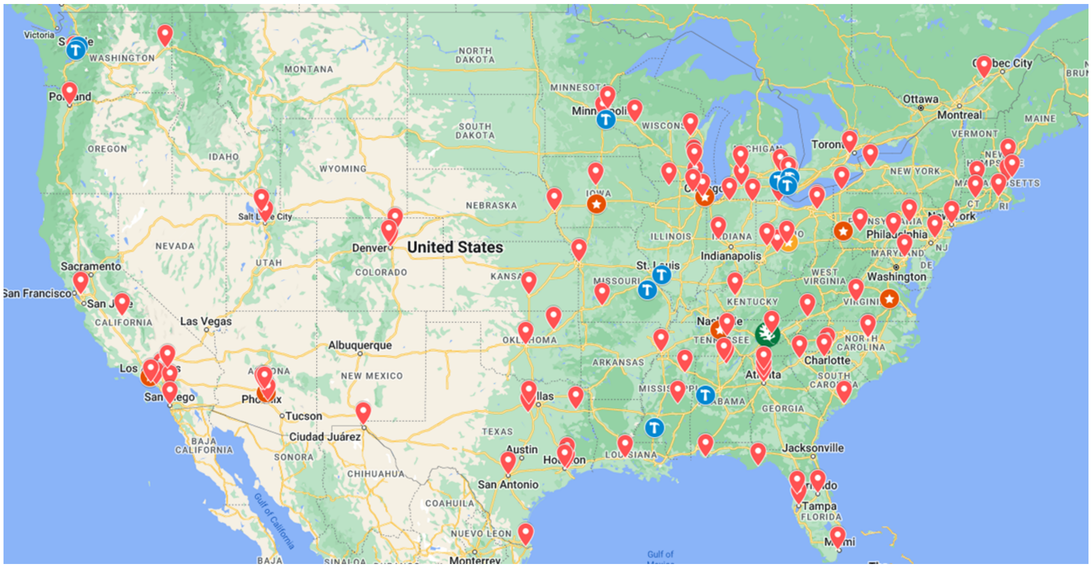

Figure 9. Locations of MSC metalworking specialists, sites indicated in red have specialists who took the machine dynamics training.

2. MSC INDUSTRIAL SUPPLY CO. BACKGROUND

MSC Industrial Supply Co. (NYSE: MSM) is the leading North American distributor of metalworking and maintenance, repair, and operations (MRO) products and services. We help our customers drive greater productivity, profitability and growth with more than 2 million products, inventory management and other supply chain solutions, and deep expertise from over 80 years of working with customers across industries. Our experienced team of over 6,500 associates is dedicated to working side by side with our customers to help drive results for their businesses - from keeping operations running efficiently today to continuously rethinking, retooling, and optimizing for a more productive tomorrow. For more information about MSC, please visit www.mscdirect.com.