ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

ULTRASONIC MACHINING

THE TECHNOLOGY

Ultrasonic machining combines ultrasonic energy and machine tools to perform traditional machine shop tasks more efficiently.

THE VALUE

Power generation facilities rely on significant machining operations, and the tool could reduce time and costs associated with a variety of jobs in new and existing plants.

EPRI'S FOCUS

Advancing the "technology readiness level" of ultrasonic machining in various applications and for technologies that can be interchangeable between full scale machine shops and more portable field applications.

TECHNOLOGY OVERVIEW

Ultrasonic machining (UM) applies intense energy (i.e. high power ultrasonics) to a standard machining process to improve the quality of metalworking. This 30 years' investigatin of a theory first investigated in the late 1950s by multiple organizations [2]. The technology gaps have been largely eliminated in the past three to four years through intense research and development at the Edison Welding Institute (EWI) in Columbus, OH. Ultrasonic machining has been demonstrated as viable for a wide range of potential power generation applications.

Historically, the application of ultrasonics to metalworking or machining processes has shown to drastically improve these operations. However, adoption of ultrasonic machining faced challenges pertaining to tool coupling, transducer power limitations, and frequency control. EWI overcame these obstacles through "shrink fit" practices, improved power supply technology, and transducer design.

The promise in ultrasonic machining lies in its ability to reduce some inherent drawbacks of machining processes (i.e. work hardening of susceptible materials, accuracy and machining rates) while advancing these processes well beyond current capabilities (i.e. better finish quality and precision, elimination of coolant). The ability for ultrasonics to improve various machining processes has been established, and multiple assessments have proven that ultrasonic machining can cost effectively increase the usability, machining rates, and potentially reduce tool wear by orders of magnitude for a range of materials, including ferritic steels, austenitic stainless steels and notoriously difficult-to-machine titanium alloys.

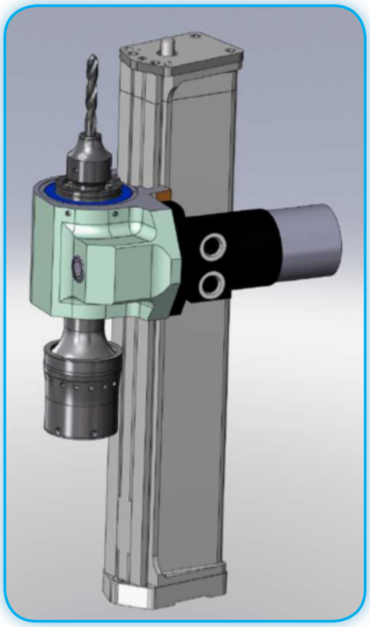

Figure 1 – Machine Drill Process Outfitted with High Power Ultrasonics Developed at EWI [1]

BASIC SCIENCE

Ultrasonic machining marries "high power ultrasonics" with normal machining process, such as milling, turning, drilling, tapping and single point turning, . High power ultrasonics uses intense, high frequency acoustic energy that can result in a change of the material being processed.

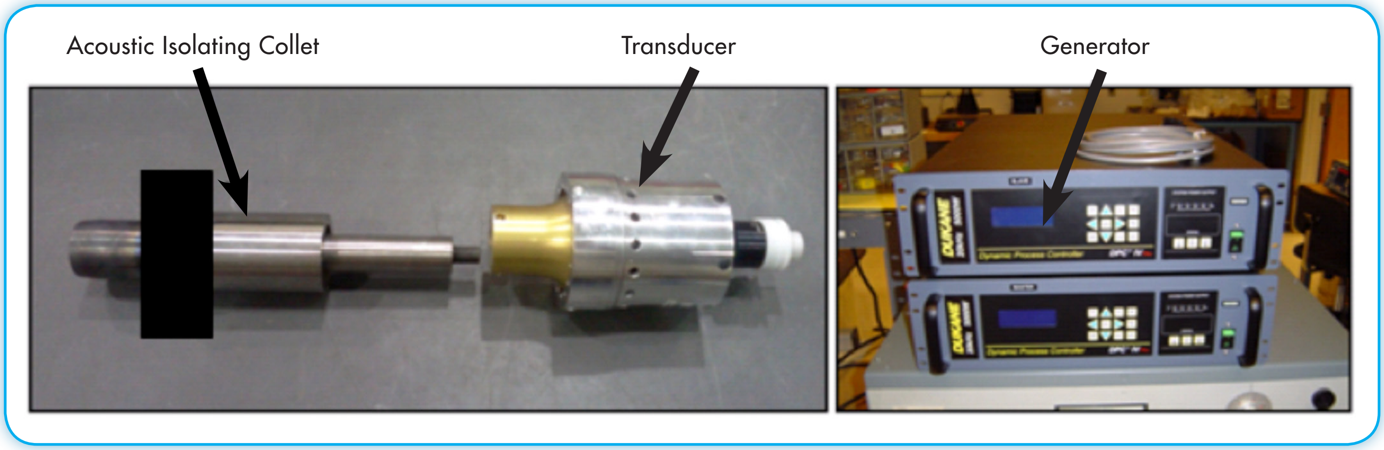

Figure 2 – Equipment Necessary to retrofit machining equipment with ultrasonic machining technology [1] Blacked out portion of the image is not yet patented

Retrofitting a conventional drill with high power ultrasonics to provide a "UM-capable" set-up requires adding key components to the drill or other machining equipment, detailed below and shown in Figure 2:

1. *Generator* –Controls power applied to the transducer. The generator can be adjusted through varying the amplitude, and is programmed to control the system frequency at a constant 20 kHZ output. A 5kW generator is typical.
2. *Transducer* – Converts electrical energy into mechanical energy (in the form of acoustic vibrations). This mechanical energy is then transferred through the collet and cutting tool into the part being machined.
3. *Acoustic Isolating Collet* –Transmits mechanical energy in the form of torque and normal force into the part.
4. *Drill bit (or other potential machine tool)* – The aim in EWI's development has been to use a bits that are standard in size and source of supply.

A new EWI design that incorporates ultrasonic machining and a computer numerical control has combined the transducer and acoustic isolating collet into one unit. This combination allows for multiple tools to be utilized with one unit rather than requiring a unique collet for each tool. This has increased the practical application of this technology to multiple platforms.

POTENTIAL IMPACT

Machining parts for fossil, nuclear or other generation applications plays a major role in fabrication. As reported by Graff, Levesque and Short, ultrasonic machining has the potential to simultaneously achieve the following [1,2]:

1. Reduce tool wear;
2. Reduce machining rates;
3. Reduce wear on machinery;
4. Reduce or eliminate the requirement for coolant;
5. Increase the accuracy of hole placement
6. Achieve very tight tolerances
7. Eliminate work hardening in susceptible materials (i.e. stainless steels or nickel-base alloys);
8. Achieve excellent surface quality and finish.

Ultrasonic machining has demonstrated a 300% improvement in tool life for titanium alloys [2]. Such improvements for a given process could result in significant cost savings and reduce/minimize scheduling issues due to machining operations. The application of this technology for drilling is ready to be commercialized today, and EWI has made a unique and concerted effort to use off-the-shelf components when developing this technology.

VALUE TO THE INDUSTRY

The power generation industry requires a considerable amount of machining, done to extremely tight tolerances. Whether drilling complex and deep holes that require extreme precision, or drilling thousands of holes for a tube-to-tube sheet, the ultrasonic machining appears suited for a range of applications in the nuclear industry, where it could significantly reduce machine time and tool wear, without the need for coolant in an industry that is extremely conscious of the coolant or lubricant utilized during machining (if allowed).

Simple machining such as drilling holes for stub-to-header connections require a great deal of material removal. Although most fossil designs involve materials that are not overly difficult to machine, the volume of parts can impose scheduling challenges during fabrication. Additionally, when the sheer number of holes to be drilled in a conventional fossil boiler is considered (thousands or tens of thousands in a new build), the potential for significantly improved machining rates is apparent.

STATE OF THE TECHNOLOGY

EWI's current work focuses on an off-the shelf ultrasonic unit that could be added to an existing platform (i.e. milling machine, drill press, etc.). Drilling has been commercially demonstrated at Areva and independently by the National Center for Defense Manufacturing and Machining (NCDMM) [1,2]. Ultrasonic machining, as it pertains to drilling, is at a TRL 8 (with a complete system demonstration in an operational environment having been completed). Remaining work through 2012 involves applying ultrasonic machining to various other operations, most notably turning and potentially to more portable field machining equipment. Currently, using UM In a turning application it is at a TRL 4.

EWI has obtained two patents. One involves a design of the combined collet and transducer module, which applies the ultrasonic energy solely to the cutting tool. This allows for the transfer of the intense energy into the tool, and not throughout the machine. The second patent covers a novel design of the acoustic isolating collet and portable assembly, which is directly attached to the transducer module. EWI is willing to license the technology.

PUBLIC LITERATURE

Many references exist regarding the application of ultrasonics to an array of manufacturing processes (such as welding and additive manufacturing) and these two areas are highly active in research and development worldwide. Few references specific to ultrasonic machining outside of slurry or abrasive assisted processes has been published.

Domestically, the only known company conducting detailed investigations and research is EWI. Worldwide, there is limited research specific to ultrasonic machining. One paper detailing the its application in an OEM drilling process was presented in 2011 at the Second International EPRI Conference on Welding and Fabrication Technology for New Power Plants and Components [1]. The most recent paper, written by researchers at EWI, summarizes the background of EWI's research in UM [2].

NEXT MILESTONE

With respect to applying ultrasonics to other machining processes, the next milestone that would likely have the greatest impact would be the application of ultrasonic technology to turning operations or to more widely utilized hand-held machining tools for field use. This could apply ultrasonic machining to widely used machining techniques and across a range of machining equipment.

The second milestone would be to establish ultrasonic machining as cost-effective. To do this, a final design review to ensure that excessive costs are eliminated in conjunction with an accurate cost benefit analysis comparing a conventional machining process to one with equipped with UM should be conducted.

INDEPENDENT ASSESSMENTS

NCDDMM performed an independent assessment of this technology, using one of EWI's milling. Evaluators measured the torque and drilling forces exerted on the drill bit during machining of 6061 aluminum using a dynamometer. Both the force and torque were reduced by 40-70%, depending on amplitude. Using the optimized amplitude, both force and torque were reduced by 67% overall [1].

Areva performed a commercial assessment in the repair of commercial vessels, and involved the drilling of many holes to access the necessary components for repair in the pressurizer. Ultrasonic machining increased drill bit life from 2 to 12 holes and decreased the time to complete the drilling of a single hole from 2 hours to 20 minutes, including setup time [1]. Selected results from the conducted assessments are shown in Figures 3 and 4. In Figure 3, the effect of ultrasonics (US) is clearly indicated with regard to the displayed tool wear after the third hole. Ultrasonic energy was effective in reducing wear, and some of the base material that was machined actually transferred onto the bit, as shown in the bottom right image.

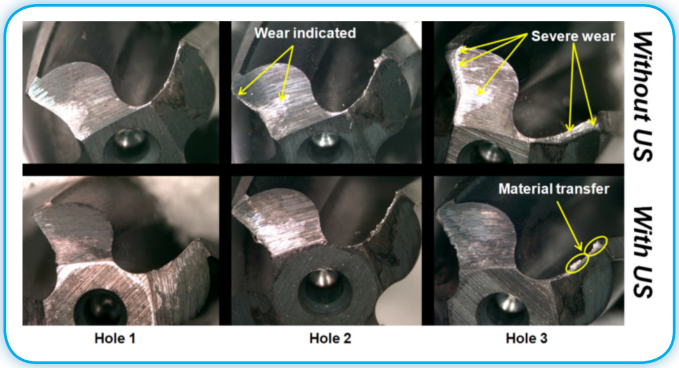

Figure 3 – Tool Wear Comparison for Machining Operation without Ultrasonics (Top) and with Ultrasonics (Bottom) [1]

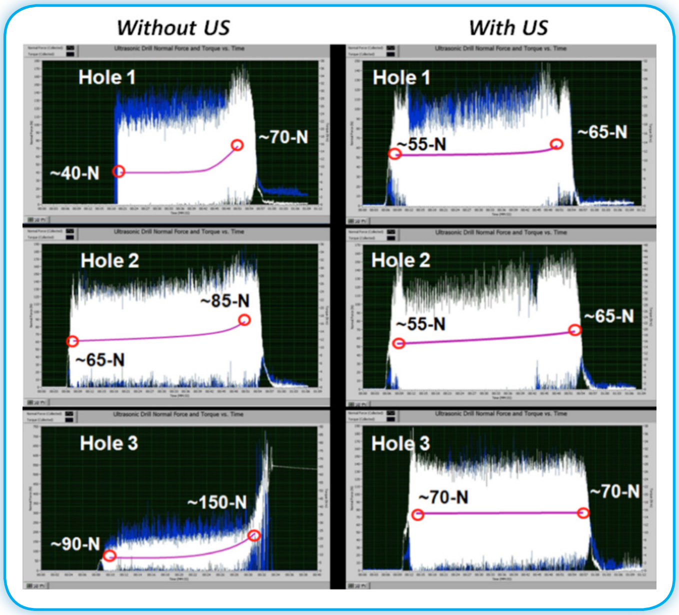

Figure 4 – Comparison of Normal Force and Torque Graphs for Machining Operation without US (Left) and with US (Right) [1]

Figure 4 shows the reduction of normal force on the drill bit during machining. The series of images on the left show an increase in required force to complete the machining operation as the bit wears by the third hole. The series of images on the right show that a machining operation with US did not show any increase in force through a series of drilled holes.

COLLABORATION

Industry collaboration with EWI is limited, and EWI has privately invested in development of the technology. Commercial involvement has been infrequent and limited to highly tailored and unique applications.

EPRI ENGAGEMENT

Ultrasonic machining for turning is at a TRL 4, while the application for drilling/milling is currently close to or at a TRL 8. The technology needs to be exposed to potential users in the utility industry and utility-directed applications. EPRI is interested in supporting this exposure as well as research to advance the application of ultrasonic machining to other machining processes.

OPPORTUNITIES FOR COLLABORATION

Potential collaborators have been identified, which could help advance the technology. Future collaboration should include an original equipment manufacturer or well-known machine that could readily employ the process for fabrication of large components. Industry awareness could be increased through an RD&D program to advance technical developments as well as process standards surrounding ultrasonic machining.

NEXT STEPS

Hurdles that need to be addressed are listed below in order of importance.

1. ***Industry awareness.*** For the power generation industry machining is vital to the fabrication of components. Cost of UM technology. An accurate analysis of the required investment to apply ultrasonic machining to existing and/or new machining equipment can help determine whether extending the technology to other machining processes is justified.
2. ***Application to a portable system suitable for field deployment.*** EWI is assessing the interest in applying ultrasonic technology to hand-held drilling equipment for routine machining of existing components in the field and/or for repairs.
3. ***Application to a CNC machine and incorporation in a manufacturing center.*** Additional development at EWI is underway in applying an ultrasonic machining module that is interchangeable with both portable machine tools and machining centers.
4. ***Application to single point turning.*** Single point turning systems, being the least developed of the machining processes will require additional research to bring the existing prototype system to industrial platforms.
5. ***Shifting industry perception.*** It represents a potentially radical shift in machining technology to machinists and manufacturers considering its deployment. Communication of its abilities, application, etc. could help to clear this hurdle to market acceptance.
6. ***Development of new machining handbooks.*** Current machining handbooks, which provide recommended procedures (such as feed rates, turning speeds, etc.) for machining different materials, are not applicable to ultrasonic machining. Creating resources such as handbooks and training guides iscrucial to the technology's widespread application.

REFERENCES

1. Poling, G. and Short, M. "Ultrasonic Machining for Nuclear Power Plant Components." *Welding and Fabrication Technology for New Power Plants and Components: Second International EPRI Conference*. Orlando, FL, June 21-24, 2011.
2. Graff, K, Levesque, S., and Short, M. "Ultrasonic Machining for Nuclear Fabrication and Primary Water Stress Corrosion Cracking (PWSCC) Mitigation." *Corrosion Solutions Conference 2011 Proceedings: 8th International Conference*. Lake Louise, Alberta, CN, September 25-30, 2011.

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