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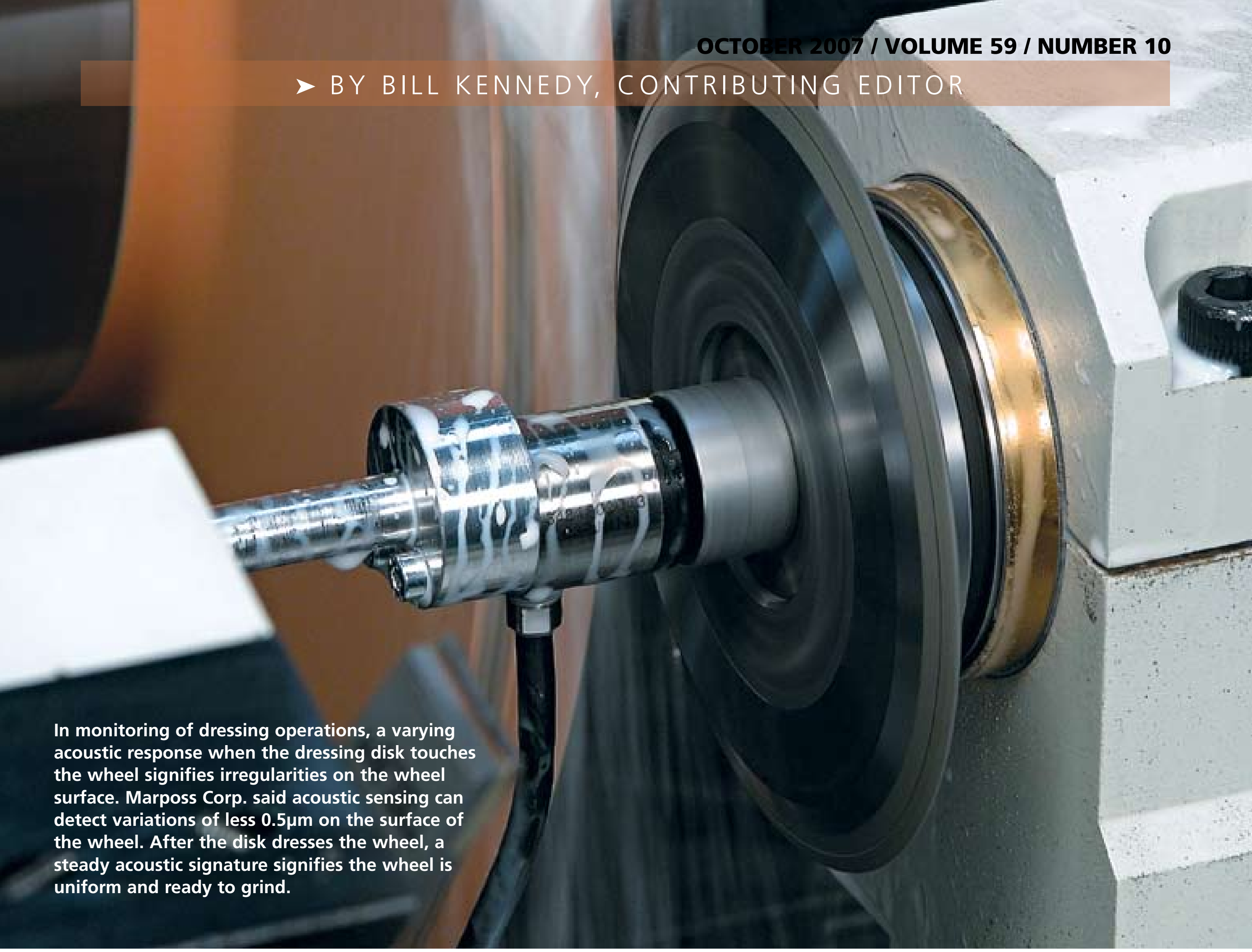
➤ BY BILL KENNEDY, CONTRIBUTING EDITOR



In monitoring of dressing operations, a varying acoustic response when the dressing disk touches the wheel signifies irregularities on the wheel surface. Marposs Corp. said acoustic sensing can detect variations of less 0.5μm on the surface of the wheel. After the disk dresses the wheel, a steady acoustic signature signifies the wheel is uniform and ready to grind.

Marposs

Just Looking

Process monitoring is a key to high-efficiency manufacturing strategies and lights-out machining.

Baseball legend Yogi Berra, who once said "You can observe a lot by just watching," may have missed his calling as a manufacturing engineer. Machining process monitoring—highly sophisticated watching—can help sustain high-efficiency strategies such as lean manufacturing, just-in-time supply and production leveling. Today's monitoring systems observe metalworking operations and react to changes to assure consistent, predictable manufacturing.

Key Requirement

According to Dean Bentzien, CEO of machine tool products provider TPS International Inc., Sussex, Wis., process monitoring is "an absolute requirement," given the growing prevalence of unmanned or semitended machining and the increasing cost of tooling, workpiece materials and downtime. The price of not detecting "something as simple as a broken tool is just simply too high to pay," he said. One broken tool can trigger a chain reaction of failed tooling. "You have downtime, you may have machine damage, you may produce who knows how many bad parts until the operator realizes he's got a problem. If you break a tool, you want to be able to shut the machine off and stop the cycle," he said.

TPS is known for its post-process, positive-contact sensor (PCS) tool breakage detectors, which use a sensor arm to physically touch the tool tip at the end of each cycle. If the tool tip is missing, the machine shuts off. At less than $1,000 per system, this type of tool breakage monitoring is effective in applications where the end user needs to check only cylindrical shank tools, such as drills, taps or endmills.

TPS International

Earlier power-monitoring systems triggered a warning or shutdown when machining loads reached a predetermined maximum value, but newer systems enable the user to observe the entire power-curve profile and set upper and lower limits. A system from Nordmann GmbH permits manual adjustment of the envelope curves using a touch pen.

Recently, in response to customer requests for a "step up," TPS introduced more sophisticated tool monitoring products. Systems from Nordmann GmbH & Co. KG, Hurth, Germany, provide post-process tool monitoring via lasers or coolant jets, ultrasound and pressure sensors. The products also offer in-process sensing to measure effective power, force, acoustic emission, acceleration and differential pressure while metalcutting proceeds.

The variety of possible metalworking operations requires a large menu of sensing technologies, Bentzien said. "Each application presents a different problem. For instance, every operation within a machine tool may not fall under a general power monitoring capability. You may need to detect a vibration problem." Bentzien said the Nordmann system can handle multiple sensors simultaneously with one control unit. "For example, in one part of the machine you need an acoustic sensor and maybe in another area you need a load monitor," he said.

The distinction between post-process and in-process monitoring also is important. Post-process monitoring offers a high certainty of breakage detection, especially with small tools, and is easy to use. But checking a tool when an operation is completed can increase overall cycle time, and waiting until a tool has broken to discover a problem may result in damage to the workpiece, machine or toolholder.

On the other hand, determining tool

condition via in-process monitoring of machine power, cutting force or acoustic emission can prevent breakage.

More than Breakage

Jim Helpling, a manufacturing engineer involved in machining hydraulic hose fittings at the Delphi Corp. facility in Dayton, Ohio, said most monitors detect a broken tool. "Breakage is not the key issue," he said. "I'm more interested in wear." Increased machine power consumption can indicate a tool is becoming worn. Therefore, power monitoring data can be used to determine when to change a tool, preventing variations in product quality and perhaps minimizing downtime for changes. Changing a tool before it becomes excessively dull eliminates the production of out-of-spec parts. Helpling noted, "I've even seen a brand new tool that is not made right. The monitor will pick that up immediately."

The rectangular hydraulic fittings Helpling typically deals with are 1"- to 4"-long and are machined from ⅝"-wide × ⅞"- thick bars of 360 brass and 1215 steel. Most of the parts are run on Hydromat HB 32/16 rotary transfer machines. Performing as many as 24 operations on a part and turning out a completed fitting every 6 seconds, the machines are of varying ages and feature different vintages of motor power-based tool monitoring.

To boost throughput and quality, Helpling regularly updates machine technology. "Whenever we redo a machine, I research everything," he said. "I take almost every component that's not part of the OEM portion of the machine and try to find the best I can. You hate to make a change, and I wouldn't unless it was something I thought was significant." He recently sought to upgrade tool-monitoring capabilities by fitting a Hydromat machine with a Nordmann system from TPS.

The system includes power-monitoring capabilities. Helpling noted that earlier power-monitoring systems triggered a warning or shutdown when machining loads reached a predetermined maximum value. Newer systems use more sophisticated software algorithms and a graphic user interface that permits the user to observe the entire power-curve profile and set upper and lower limits.

To illustrate the benefit of viewing the entire profile, Helpling used the example of a multistep tool. "The peak load is going to be when you hit that second step," he said. "But if you have an issue [such as wear or breakage] with the smaller diameter, you'll never see it unless you are monitoring the whole profile." The information gathered can be applied in different ways. "You can set it up where you can have two alarm levels. One says the tool is getting dull and as soon as you get a chance, change it. Or you can choose to shut it off as soon as you hit that alarm," he said.

In addition to monitoring the entire power consumption profile, the system can be set to focus on a small segment of it. "You determine a certain area of your load profile is a critical feature on your part, and you can choose to monitor that area real closely," Helpling said. He cited the case of a combination tool that drills and counterbores. "That counterbore is critical. The drill is just a roughing tool. So in that particular case, you put higher limits on the drilling portion, but finer limits on the counterboring portion so you can really tune that area in and not have a bunch of nuisance shutdowns for the drill."

According to information from Nordmann, the most significant benefit of tool monitoring is the ability to run a machine semisupervised, which can reduce machining costs by up to 30 percent. Extension of tool-change intervals by predicting and detecting wear, as opposed to scheduled tool changes, can save another 2 to 8 percent in costs.

Adaptive Advantage

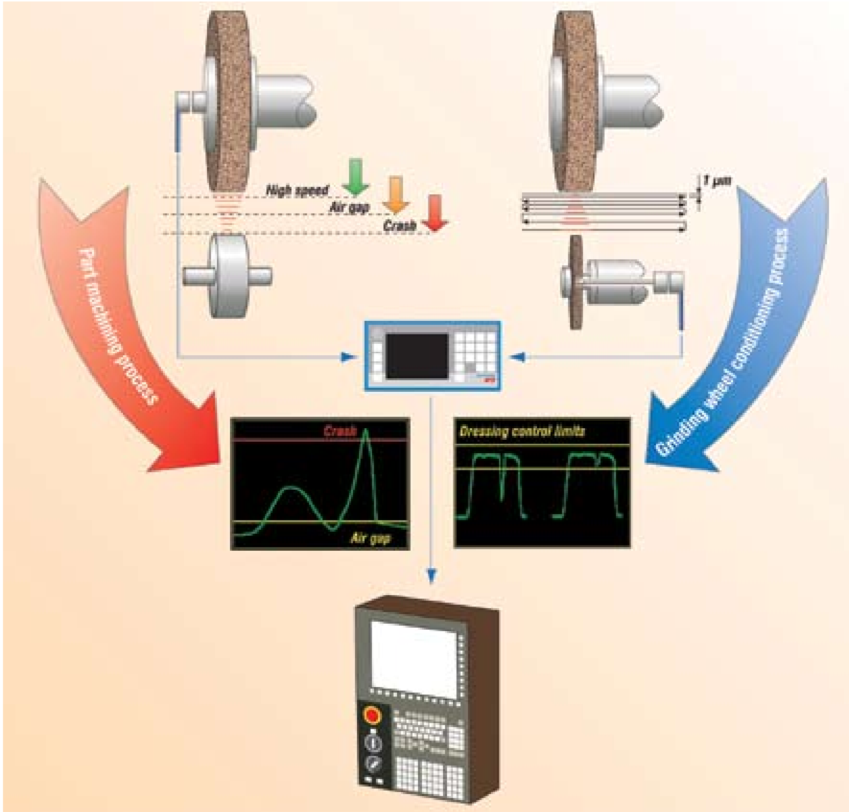
John Maher, president of Artis Systems Inc., Livonia, Mich., said interest in tool monitoring is growing. He added that many manufacturers, especially aerospace companies, now provide specific tool-monitoring performance guidelines and requirements. "They want that data for quality control before the part is even accepted," he said.

Maher said process monitoring encompasses three areas. Tool monitoring detects worn, broken or missing tools. Machine condition monitoring uses sensors to detect excessive vibration and torque loads that can affect the machine itself. The third area, "where real dollars can be saved," Maher said, is process optimization that includes adaptive, real-time control of cutting parameters. In addition to boosting productivity, adaptive control increases tool and machine life, he said.

Artis Systems' process monitoring system is based on a PC plug-in computer-integrated tool and machine monitoring (CTM) card that is inserted into a slot in an open-architecture CNC. Via a sensor bus, the card can receive input from external power, force, torque, acoustic and vibration sensors. It can also directly monitor torque signals generated by the machine's spindle and axis drives through a feature called digital torque adaptation. "That information is right there in the machine," Maher said. Values from the spindle and X, Y and Z axes can be weighted, summed up or randomly assigned to the card's four channels.

In adaptive control mode, the CTM card employs a code that reads the information from the tool and machine and overrides the programmed machining parameters to increase or decrease feed rate as needed. Feed rate increases when the tool is cutting air or metal-removal requirements are not high, and decreases when the part profile puts heavy loads on the tool and machine.

Maher said adaptive control is geared toward specific processes "like milling, where you are taking off large chunks of metal. It's not really for fine machining. In roughing, you can have substantial cycle time savings." Because the reduced feed rates protect the tool, "you can get increased tool life as



Marposs

Acoustic sensing in grinding operations detects wheel/part contact and prevents crashes (left) and determines when dressing is complete, thereby limiting unnecessary wheel wear.

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well," he added.

The adaptive system usually operates within constraints set by the machine user, Maher said. For example, in demanding aerospace applications, the override range may be limited to ±10 percent of the programmed machining values. Aerospace parts are often extremely expensive and a manufacturer wouldn't want to take the risk of using a 30 percent override factor because aggressive machining parameters increase the possibility of damaging the part.

Adaptive control can make a substantial difference in productivity. Artis reported that adaptive control of cutting tools when machining aluminum ABS pump casings at Robert Bosch GmbH in Germany enabled cycle time reductions and minimized tool breakage. Typical cycle time reductions from using adaptive control range from 7 to 15 percent.

Maher added that by combining the input from different sensors, the Artis system creates a customized monitoring signature for a particular part. "Say it alarms in one area, but it doesn't alarm in another area," said Maher. "We need both alarms to know we really have an issue." For example, spindle load information may be combined with tool breakage detection. If the spindle momentarily experiences high loads, but tool breakage doesn't occur, the spindle sensor will reset. The operation can continue without a shutdown or triggering of a warning. However, simultaneous problem messages from both sensors will trigger operator notification.

Spindle load information may be combined with tool breakage detection. If the spindle momentarily experiences high loads, but tool breakage doesn't occur, the spindle sensor will reset.

Different Vibrations

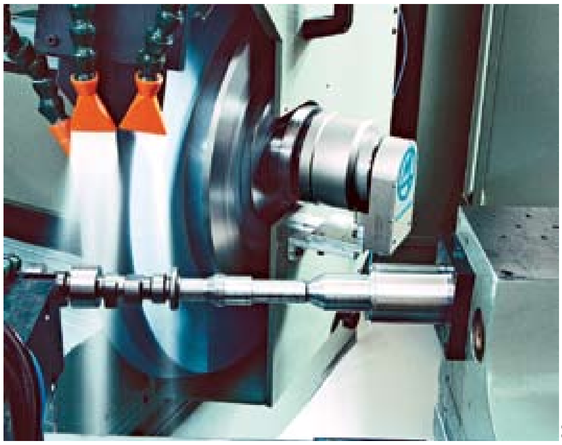
Monitoring of grinding processes focuses on wheel dressing, detecting and curing wheel imbalances and cycle time reduction. Giordano Falchieri, product manager, Marposs Corp., Auburn Hills, Mich., said the sensing technologies employed in grinding generally involve monitoring different levels of vibration.

For dressing and wheel/workpiece contact, acoustic sensors measure vibrations in the range of about 50 to 1,000 kHz. In monitoring dressing operations, acoustic sensors are mounted on the grind wheel flange, tailstock, dressing tool or in the dressing spindle. When the dressing tool touches the wheel, a varying acoustic response indicates wheel surface irregularities. After the tool dresses the wheel, a steady acoustic signature signifies that the wheel is uniform and ready to grind. According to Marposs, acoustic sensing can detect variations of less than half a micron on the surface of the grinding wheel.

Acoustic monitoring enables dressing to be halted immediately when a wheel reaches uniformity. The cost of grinding wheels, especially CBN wheels, dictates minimum dressing to reduce wheel wear.

Acoustic monitoring can also help minimize grinding cycle times. Falchieri said: "When a part is loaded, the wheel is in the home position, relatively far from the part. It's imperative to move the wheel into contact with the part as quickly as possible. But you want to avoid crashing into the part." An operator can advance the wheel quickly, then slow it down as it approaches the part. But that requires leaving a safety margin, which wastes time. Governed by an acoustic sensor, the wheel can advance rapidly until it touches the part. "Once you touch the part, you immediately have feedback from the acoustic control and you slow down. You don't damage the part or the wheel," said Falchieri.

A different sort of vibration in a wheel/spindle assembly results from mechanical aberrations, such as inconsistencies or gaps in the wheel's grit/binder mix, uneven wear, coolant absorption or incorrect mounting of the wheel relative to the grinding spindle. This sort of vibration is steady and will continue until action is taken to stop it. Controlling these vibrations is vital because they impair the grinding process and can eventually damage the wheel and the grinder itself. According to Falchieri, these types of low-frequency imbalance vibrations are best measured with an accelerometer.



Marposs

An imbalanced grinding wheel/spindle assembly will degrade part quality and can eventually damage the grinder itself. An automatic balancing system, such as this flange-mounted balancing head from Marposs, monitors via an accelerometer the low-frequency vibrations that result from imbalance and automatically shifts weights within the balancing head to restore balance.

A wheel/spindle assembly can be balanced manually, but it takes time and skill. Marposs provides an automatic balancing system that consists of a balancing head in the flange (typically retrofit situations) or inside the spindle (generally available on new machines), an accelerometer-type vibration sensor and an electronic control unit. The balancing head uses compensating weights to counteract the imbalance, much like weights are clamped on an automotive wheel to balance it. The balancing process, Falchieri said, "happens automatically during the time the wheel is spinning."

Advanced Health Benefits

Jim Dallam, development manager for the MAG Advanced Technologies division of MAG Industrial Automation Systems LLC, Cincinnati, observed that monitoring systems can benefit machine health, as well as process health. He said while a monitoring system can be used to avoid chatter on a specific cut or optimize a cutting operation, monitoring information can also be used for predictive maintenance. "You could potentially sense an impending mechanical failure and take corrective action," he said, adding that "you are applying the same technology for two different goals."

MAG IAS is developing a number of technologies on the machine health side of the monitoring equation. One is an embedded control monitor that tracks vibration severity levels as machining proceeds. Rich Curless, vice president, product technology and development, said the system will record "a histogram of severity levels, so we can take a look at what's gone on for the history of that spindle on

MAG IAS

MAG IAS researchers note that monitoring systems can benefit machine health as well as process health; while monitoring systems can be used to avoid chatter on a specific cut or optimize a cutting operation in general, the information acquired can also be a basis for predictive maintenance.

that machine tool—how many hours at idle, how many in mild cutting, how many in heavy cutting and chatter. With that, we can start to determine the life expectancy of spindles."

The information would enable MAG IAS to advise customers regarding spindle application and care. "The logging system allows us to understand the history of our devices, and we also are working on preventive maintenance features," Curless said. "Like other machine tool companies, we are developing new technologies that will enable real time understanding of what conditions the machine is facing. That information will allow users to prevent damage or to do maintenance before a machine breaks down."

He added that while spindle suppliers have begun to provide temperature, vibration and other sensors in their products, the systems are typically expensive—about 10 percent of the cost of a $40,000 to $50,000 high-performance spindle. While sensing technology is usually added to expensive spindles, it is not seen as affordable on more basic units. "What about the job shop? There are tons of spindles out there that need to be monitored," Curless said.

As a result, MAG IAS is seeking to develop affordable spindle monitoring, based on simplifying the systems and choosing the right conditions to monitor. Curless used the example of monitoring spindle temperature, which, intuitively, would seem to be a good predictor of spindle health. However, MAG IAS found temperature generally remains normal or may even drop before spindle failure occurs. In the case of a lubrication interruption, the oil film in the bearing thinned and temperature actually fell because the thinned oil film briefly reduced resistance. When the bearing cage broke or the spindle finally seized, the temperature suddenly skyrocketed. As a result, temperature sensing "wasn't very predictive," said Curless.

On the other hand, MAG IAS researchers found that vibration can be a significant predictor of a spindle's future health. "When a spindle's systems fail, it's typically due to vibration," Curless said. Vibration can cause coolant unions to shake loose or drawbar systems to lock up. "We need better ways to evaluate spindles," Curless said. "If we optimize and pick the right conditions to monitor, we can cut our costs and deliver a more effective solution."

Dallam said it is crucial to develop these promising technologies from R&D prototypes into products that are robust and reliable on the shop floor. Mark Logan, MAG IAS vice president of business development and marketing, said "to successfully operate in a lean environment—and we all need to—we must avoid any unscheduled downtime or maintenance. Monitoring systems contribute to what we all want, which is a very robust, predictable process." △