A two-channel, through-tool minimum-quantity lubrication setup.

bielomatik

By Alan Richter, Editor

Tool Spray

The benefits of through-tool minimum-quantity lubrication can be called 'green' because they're environmentally friendly and help boost the bottom line.

Talk about a win-win situation. Minimum-quantity lubrication, or near-dry machining, significantly reduces coolant consumption, associated equipment and energy costs, airborne particulate emissions and the likelihood of workers experiencing skin irritations, while potentially increasing productivity and part quality. This is the case for through-tool MQL—the focus of this article—and externally applied MQL.

Instead of flooding the tool/workpiece interface with coolant, through-tool MQL applies an aerosol of compressed air and lubricant, typically vegetable, ester or alcohol based, through the spindle and out the tool through coolant holes, directing the mist specifically to the cutting edges. With optimized dosing, about 90 percent of the fluid is consumed during the cut, most of the remainder travels with the chips, and the part has little to no residue, according to Kevin Howes, North American sales manager for bielomatik Inc., New Hudson, Mich., which makes MQL delivery systems. He added that an MQL system uses about 10 to 150 mL/hr. (0.003 to 0.04 gph) of lubricant vs. up to 132 gph or more for wet machining based on a 5 percent emulsion.

The general consensus is that switching from wet to near-dry machining can reduce coolant-related costs by 10 to 17 percent. "People say they don't spend that much on coolant, but they don't take into consideration all the other costs," Howes said. "They're thinking about the coolant itself."

Learn more about minimum-quantity lubrication

An expanded version of this article, with additional information and graphics, is featured as an Interactive Report on www.ctemag.com. The new CTE Plus features a range of Interactive Reports, a virtual product showcase, daily industry news and the CTE Community.

The other costs include filtration systems and media, tanks, recirculating chillers, high-pressure skids, centrifuges or briquetters for removing coolant from chips, and biocides. In addition, Howes said when building a green site facility using MQL, special foundations are not required to support heavy coolant filtration systems. “They just pour a flat floor of a certain thickness for the machinery,” he said.

Some part manufacturers might say their flood coolant is filtered and reused, but that doesn’t mean all of it stays in the system. “Customers have told me the amount of coolant loss is unbelievable, especially on older machines,” Howes said. This loss is caused by evaporation and leaks, as well as being “sucked out” by a mist collector during cutting. End users estimated a coolant loss of ½ to 1 gal. per part in a production environment. “If you’re making 250,000 parts a year, that’s potentially 250,000 gal. of coolant loss,” Howes said.

System Choice

In MQL, there are two basic methods for mixing the air and lubricant before delivering them through the tool: one- and two-channel systems. A one-channel system mixes the two components in a tank behind the spindle. The mixture is then transported via a pipeline through a rotary union and to the tool head via the spindle or turret.

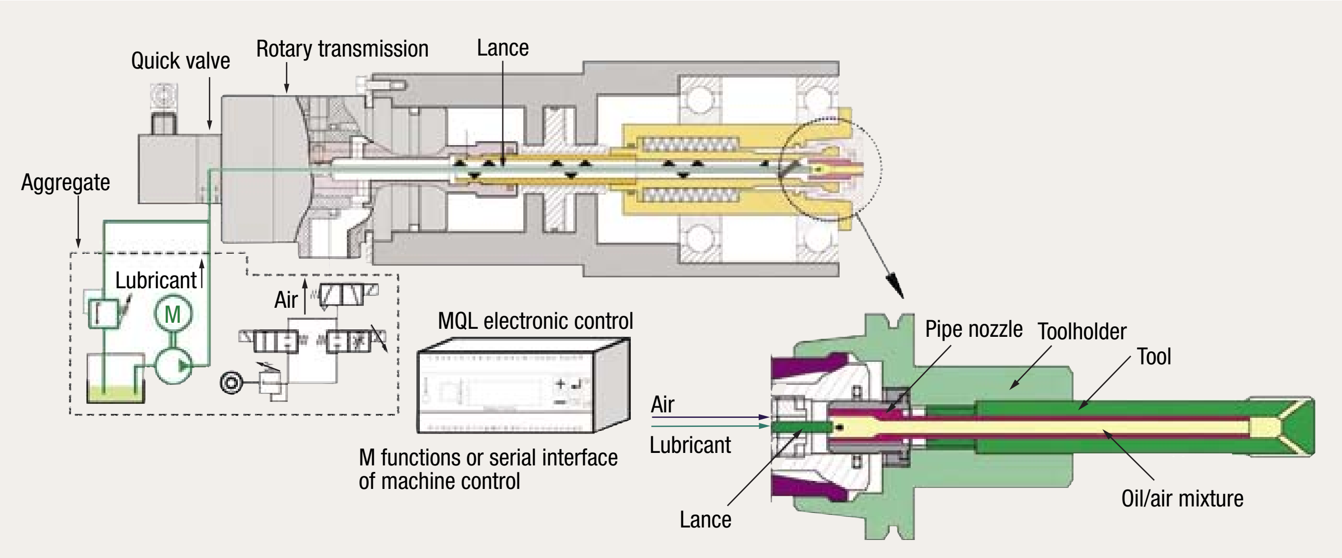
A two-channel system, on the other hand, is a recirculating-type system where oil is continually pumped from a tank and back in a ring line. To provide a specific fluid dose, a quick valve prior to the rotary transmission regulates the amount of lubricant entering the system. “As required for the MQL operation, a quick valve is turned on and optimally doses the amount of oil drawn from the ring line,” said Howes.

The oil is transported through a lance in the center of the spindle to a pipe nozzle at the toolholder’s base. As lubricant moves through the lance and into the pipe nozzle, air supplied through the rotary transmission travels down the spindle coolant tube that encapsulates the lance to the mixing chamber of the pipe nozzle, where the air combines with the fluid to form an aerosol. This aerosol then travels through coolant holes inside the tool and is dispensed as fine oil/air particles.

Spindle speed is a factor in selecting a one- or two-channel system. A one-channel system mixes the fluid and air before it travels through the spindle, so the maximum spindle speed is about 16,000 rpm. That’s because the centrifugal force of higher speeds may cause the fluid to separate from the air. “That’s not a hard number,” Howes said about the spindle speed, adding that a two-channel system is suitable for speeds up to approximately 40,000 rpm.

Also, the distance the aerosol can travel is limited for a one-channel system, with about 50' being the maximum distance before it breaks down. That’s not an issue for a standard machining center, but Howes said a large gantry-type machining center would require mounting a one-channel system onto the gantry itself so it moves with the gantry rather than placing the system on the plant floor and transporting the aerosol.

Another consideration is tool-change frequency because a one-channel system requires a lag time for the aerosol to travel from the back of the spindle to the end of the tool. “In the single channel, you create a dwell in the tool-change program,” said Mark Blosser, di-



bielomatik

In a two-channel MQL system, the precise amount of oil is transported through a lance to a pipe nozzle located at the toolholder's base. As lubricant moves through the lance and into the pipe nozzle, air supplied through the rotary transmission travels down the spindle coolant tube that encapsulates the lance to the mixing chamber of the pipe nozzle, where it combines with the fluid to form an aerosol.

rector of solution business for Komet of America Inc., Schaumburg, Ill., a maker of taps, reamers, drills and boring tools for MQL applications. "In the two-channel, it's virtually instantaneous."

The lag time between a tool change is 1 to 3 seconds with a one-channel unit, according to Howes. "With a two-channel system, when you shut off the MQL, all you're doing is stopping the MQL flow going into the toolholder," he said. "You're only looking at 0.1 to 0.3 seconds for the MQL to start flowing again."

Howes added that a one-channel system, which is about 90 percent of the cost of a two-channel system, could be programmed to turn the MQL on a bit earlier before entering the cut to reduce the lag time but then more oil is consumed. "When you look at the overall cost savings, two-channel systems seem to have the benefit," he said.

Nonetheless, a one-channel system offer benefits, especially for lower and medium-volume parts manufacturers that need to switch back and forth quickly between wet and near-dry machining based on workpiece considerations. That's because a one-channel system introduces aerosol into the back of a rotary union the same way it would for flood coolant. With an extra ball valve and piping going into the rotary union, "you'd either turn one ball valve on for coolant and have the other ball valve closed for MQL or vice versa," Howes explained.

Possible Limitations

MQL may not be appropriate for machining all workpiece materials. Alan Shepherd, technical director for toolmaker Emuge Corp., West Boylston, Mass., recommends against applying a minimal mist when tapping the "nastier" stainless steels, titanium and some nickel-base materials, like Inconel. More than a mist may be needed. "You're not going to cut them without some sort of fluid," he said. "There are limitations to what you can do with MQL." Emuge designs and manufactures taps for MQL applications.

Others indicated that the workpiece material wouldn't restrict applying MQL as long as the toolmaker properly designs the cutting tool. "Every tool needs to be modified based on the operation and the material," said Blosser.

Wally Boelkins, CEO of lubrication system builder Unist Inc., Grand Rapids, Mich., concurred. "We do everything—all the exotic materials and the high-nickel stuff," he said. "It doesn't bother us at all."

Unist equips spindles with one- and two-channel MQL systems, as well as offering external MQL delivery. Boelkins said two-channel systems are preferred but sometimes cannot be installed. "Rotary unions [for two-channel systems] are attached at the top dead center of a spindle, and sometimes the openings don't come into the spindle at top dead center," he said. "There are many machines not really equipped for two-channel systems."

The type of operation also impacts MQL's effectiveness. For example, Ford Motor Co., which has all its 200 MQL machines in the U.S. equipped with two-channel systems, applies MQL for all metal-removal requirements except grinding and honing, said Alexander Stoll, the automaker's powertrain technical expert (MQL core engineering). He's currently based at Ford's Technical Center in Dunton, England.

Stoll said Ford hones engine blocks and some differential cases. "However, honing is a niche application for MQL, and we haven't put too much focus on the honing process yet," he said.

Boelkins said MQL is appropriate for some grinding applications, such as tool and cutter grinding and potentially surface and hypodermic needle grinding. "For big centerless grinding operations, MQL may not be the best way to

Back in round

A PARTS MANUFACTURER was facing an out-of-round problem with its bores. Bore roundness ranged from 12 to 20 microns, with the maximum allowable roundness being 12 microns.

The company was also facing a slow cycle time. The part has many bores and the time to machine each bore was simply too long. Finally, because of the high minimum quantity-lubrication delivery rate of 250 mL/hr. applied to achieve the surface finish specification, the parts and chips were dripping in oil.

Unimerco Inc., Saline, Mich., tackled these issues by providing a special PCD tool—the Heli-Ream. The Heli-Ream has a slight helix, which lowers cutting forces. In other words, the tool exerts less pressure on the part. The results were less vibration and significantly better roundness. Roundness improved from 0.017mm on average to 0.0022mm—less than 3 microns.

Second, because of the lower cutting forces, feed rates were increased more than fivefold from 500 mm/min. to 2,800 mm/min. The company was able to increase the spindle speed from 7,000 to 8,000 rpm, too.

Also, the Heli-Ream allowed the company to run at a lower MQL delivery rate of 80 mL/hr., so the chips and machined parts were no longer dripping in oil.

It turns out that the slight helix helps draw chips out of the bore, something that is extremely important when near-dry machining. Traditionally, water-based coolant is used to help evacuate chips, and this coolant becomes even more important at high feed rates. But in an MQL environment, where there is little fluid to flush chips, the Heli-Ream's slight helix can help evacuate chips.

—Jim R. Stead, sales manager, Unimerco Inc.

go," he said.

Key Improvements

Ford, which started using MQL in Germany in 1998, said for typical mass production modules the introduction of MQL helps to reduce annual coolant consumption by about 30,000 gal., water use by 250,000 gal., filter media usage by several thousand yards and compressed air usage by millions of cubic feet. In addition, Stoll said the automaker's recent work with near-dry machining yielded five key improvements. The first was development of an FMEA (failure mode and effects analysis), which presents lessons learned and helped create training materials and documentation to assist the workers.

The second was development of a calibration routine for calculating the air and oil flow. Without one, 50 machines with 50 MQL supply systems could come from the same supplier but perform differently. "You have to calibrate them to the same baseline," Stoll said. "Previously, no good calibration methods and devices were available."

The third major improvement was development of optimal interfaces between the tool, toolholder, pipe nozzle, adjustment screw and lance to ensure the aerosol traveled in a straight path through the system and out the tool without any voids, or cavities, which would divert the aerosol flow.

The fourth significant improvement was development of MQL spray-pattern testing to verify that cutting tool designs optimized mist flow as indicated via simulation.

The final improvement was integrating sensors in the part fixtures, machine bed, column and spindle to monitor machine and part temperatures and then use this in-process data with linear expansion algorithms to adjust the spindle's position.

Oil Issues

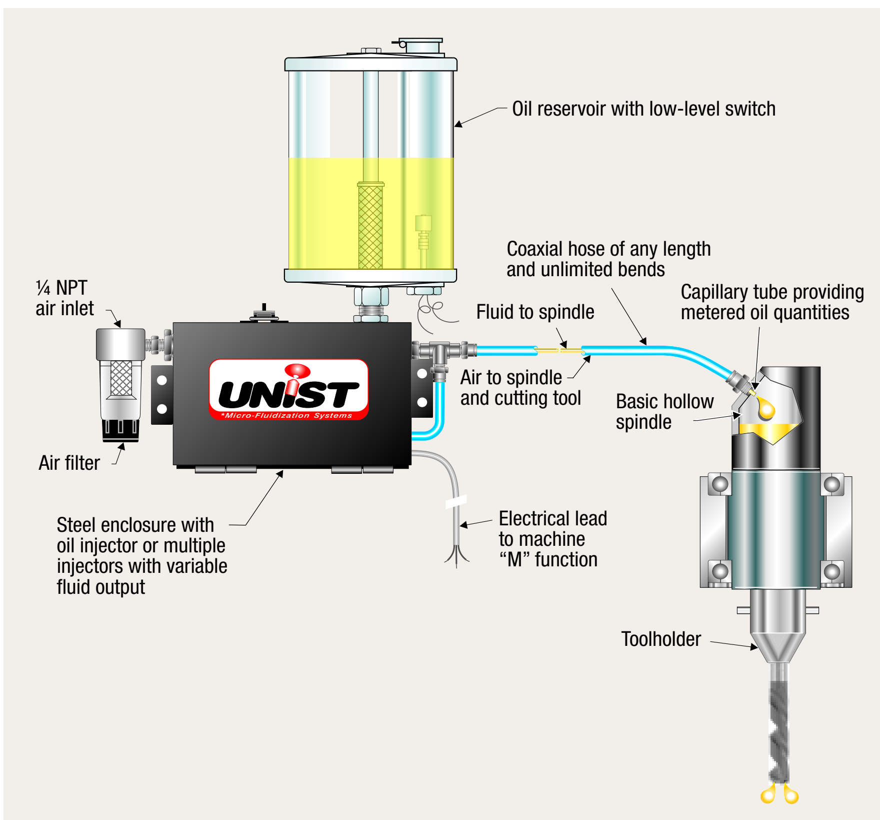
Stoll said it may help if oil is at a constant temperature to ensure a constant oil viscosity and therefore a consistent dosage at the cutting zone. However, a facility's temperature may swing from 60° F to 110° F, depending on the time of day and season. Therefore, Ford and bielomatik installed a heating unit on the quick valve to increase the oil's temperature above that of the ambient plant air.

The type of oil is also critical to making MQL successful. Unist's Boelkins said part producers need to avoid using "an inexpensive fluid" that oxidizes. "The oxidation properties cause the fluid to become sticky and build up varnishes on surfaces that can be easily removed—with a hammer and a chisel," he said. "The stickiness can really be a problem when chips start sticking to each other and to the tools. You get chip recutting."

Instead, Boelkins recommended applying a mist containing a highly refined vegetable oil, also known as an ester. "By using a small amount of very good, relatively expensive oil and compressed air, there's zero resistance to the chips, and they fly out of the hole [when drilling]," he said.

Boelkins added that vegetable oil provides a significantly higher heat capability compared to mineral oil, with a flash point of about 450° F for vegetable oil vs. 250° F for mineral oil.

He also warned against applying a vegetable oil as a fog because the tinier the particles, the less likely they are to "wet out" on a tool surface. "From a



Unist

A one-channel, through-tool MQL system.

health standpoint, although it's nontoxic and biodegradable, vegetable oil can still get into and coat lungs, and the tinier the particles that get into your lungs, the more destructive they are," Boelkins said.

Near-Dry Tooling

For best results, toolholders and cutting tools need to be adapted for near-dry machining. Any type of toolholder is appropriate for MQL applications, but HSK is the most popular, in part because European machine tool builders have driven MQL development and HSK holders are popular there. The critical factor compared with wet machining is there's a clearly defined transport path for the aerosol to follow without any voids to disturb the velocity and flow.

According to Dave Smith, president of toolholder manufacturer T.M. Smith Tool International Corp., Mt. Clemens, Mich., the connection inside the back of the toolholder to the spindle determines how it routes the coolant to the cutting tool. "Externally you wouldn't notice the difference, but internally you would," he said about the variations in toolholders for wet and near-dry machining. "You want the specific amount of mist to go through the toolholder right to the cutting tool."

Komet's Blosser added that the radial adjusting screw for setting tool length and the back of the tool shank's interface to the toolholder is the only thing that changes. "You're able to take a standard adapter, take out the screw, use an MQL-compliant coolant pipe, which comes from the machine tool builders, depending on the type of delivery system, and then change the adjusting screw," he said. "Then you have an MQL-compliant toolholder."

In contrast, cutting tools need more modification for MQL. When hole-making, for example, the exiting ports of a drill's coolant holes need to be enlarged to help deliver coolant to the drill's entire rake face that contacts the workpiece to eliminate built-up edge and thermal tool quenching, Blosser said. Thermal quenching occurs when coolant is introduced to the hot tool/workpiece interface during cutting. This quenching breaks down the tool's

Clearing the air

AT LARGE U.S. AUTOMOTIVE factories, more than 100 MF-Sorp units for minimum-quantity lubrication machining centers treat exhaust air coming from gear and engine production centers. The MF-Sorp system, available from Dantherm Filtration Inc., Thomasville, N.C., integrates source capture devices, pipe accessories and chip collectors for each machining center to provide flexibility at the production site.

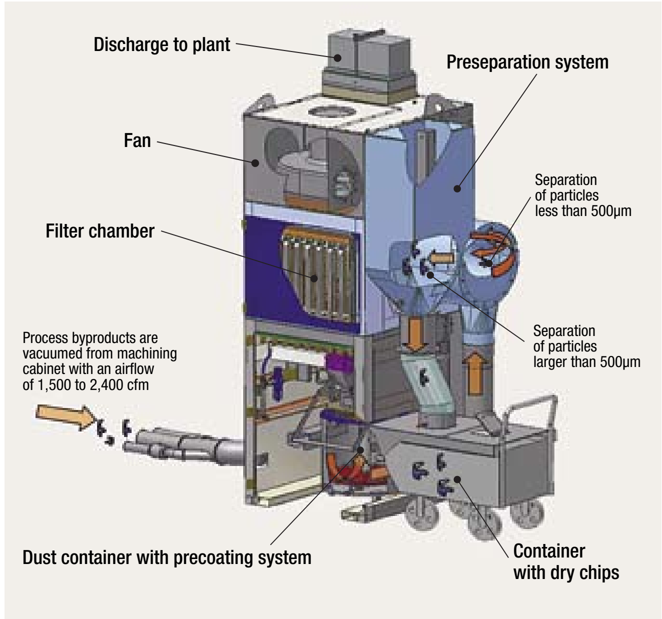
In many cases, up to 90 percent of the exhaust air can be cleaned and recycled back into the working area. This significantly lowers energy costs.

Chips, metal dust and, in most cases, oil vapor are captured and extracted to prevent the formation of a potentially explosive mix of air, vapor and dust.

The process first separates larger, nonflammable chips in a preseparation system and collects them for recycling. The remaining dust and air is then introduced to the particle filter surface along with special additives that render aluminum dust inert. With an MF-Sorp system, conventional chip conveyors can be eliminated.

Also, sticky oil droplets from MQL machining operations are separated from the exhaust airstream and deposited onto the precoating layer consisting of an inert lime-like substance, which prolongs filter life because the droplets no longer clog the downstream filter layers. Additional deep-bed filters or secondary filtration phases are not required to consistently achieve clean gas values of 0.01 mg/m^3, which is a measurement of the particles in the exhaust airstream.

—Dantherm Filtration



Dantherm Filtration

The MF-Sorp system captures and extracts chips, metal dust and, in some cases, oil vapor to prevent the formation of a potentially explosive mix of dust, vapor and air.

substrate and shortens tool life.

"You also want to reduce the crowning point of the drill geometry to supply as much coolant to the center of the drill as possible," Blosser said. In addition, flutes need to be highly polished to prevent chip binding.

Tool designers must consider that the air/oil mixture needs to reach all the cutting edges in multiple-step tools. With longer tools, the internal coolant port must have a smaller step down at the end of the tool. "You create a vortex to accelerate the coolant to the end of the tool, so all the cutting edges have ample lubrication," he said.

The size of the exiting holes is also based upon the channel diameter in the tool shank. "If the main diameter in the shank itself is 6mm, the sum of the exiting holes cannot exceed the volume based upon a 6mm hole," Blosser said. This is because there will be a loss of pressure and therefore velocity if that sum exceeds the volume.

Blosser noted that internal applications are the most demanding for near-dry machining. "Normally, on a conventional application, you would run milling tools dry anyway."

Therefore, tapping requires carefully designed and manufactured tools for MQL as well. Emuge's Shepherd said a specific tap's design depends on the workpiece and threading application, but compared with conventional taps, taps for near-dry machining have a higher relief angle, higher back taper and narrower lands for synchronous tapping, which is desired. "What you don't want is a lot of contact between the cutting tool and the part," he said, adding that a tap's flanks shouldn't be rubbing. "You want to able to control the feed going in and the feed coming out so it's synchronous."

How an MQL tap's coolant holes are produced depends on whether it's for a blind- or through-hole application. For through-hole tapping, Emuge

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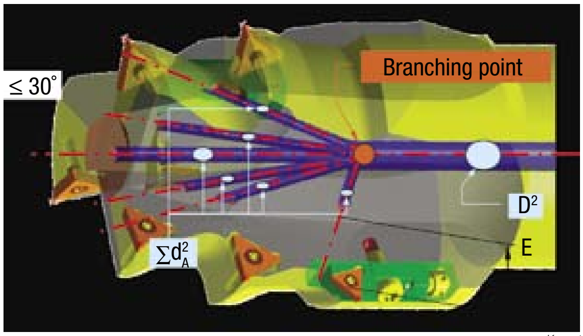
EDMs a coolant hole through the tool's length, plugs the end of the hole and EDMs cross-holes so the mist exists the side of the tap. "If we didn't do that, then the minimal mist would just shoot down through the bottom of the hole and have no effect," Shepherd said. For a blind-hole application, the hole through the tap isn't plugged, allowing the 100- to 200-psi mist to travel to the bottom of the hole to perform its lubrication and chip-evacuation functions.

Ford's Stoll said toolmakers should first test an MQL tool design to make sure the mist is exiting the coolant hole as close as possible to the cutting edge. "Sometimes it helps if the coolant holes are even in front of the cutting edge," he added.

He recommends using the previously mentioned MQL spray-pattern testing. The test involves placing a sample tool in a machine's spindle with an MQL supply system, positioning an absorbent medium green or blue surface about ½" in front of, underneath or around the tool as it rotates and noting the position of the oil in relation to the cutting edges. If the spray pattern aligns closely with the cutting edges' location, then there's a high probability the tool will function properly.



A step boring tool for MQL. For a two-channel system, the following equation applies: $\sum_{i=1}^{n} d^2$ (exit) $\leq D^2$ (entrance)

"Produce one tool first or a surrogate/dummy tool, put it onto a machine and do a dynamic spray-pattern test," Stoll said. "If the tool fails, then go back to engineering."

Productivity and Part Quality

Minimum-quantity lubrication can enable running at higher speeds and feeds in part because coolant isn't limiting machining parameters, especially when holemaking. For example, many companies are going from a gundrill to a twist drill for small deep-hole drilling. "More stuff going on in the hole isn't always better," said bielomatik's Howes. "You've got high-pressure coolant in the hole, and it's battling for space to evacuate the chip where MQL uses the air to evacuate the chip out of the hole."

Coolant can also slow machining by thermally shocking carbide cutting edges as heat is being generated in the cut. "With MQL, you don't get that thermal cracking of the cutting edge because you don't quench it or create any stress fractures or cracks in the carbide," Komet's Blosser said. "That enables you to run at a little higher surface footage than you normally would with a wet-type application."

Stoll concurred that machining parameters were higher for certain MQL applications vs. wet machining. In one drilling application, for example, Ford upped the feed rate from 125 mm/min.

when wet machining to 660 mm/min. with MQL. But he added that some applications were slightly slower with MQL. "Overall, there is no cycle time penalty when going near dry, but usually it offers a time advantage," Stoll said. "Probably the less complex the component, the higher the chance that you can go faster and improve quality with MQL."

Part quality in terms of surface finish often improves when switching to MQL because virgin oil is applied every time rather than recycling coolant when wet machining and potentially introducing abrasive fines into the coolant and therefore recutting them.

Shepherd said MQL is a slow growing trend, but understanding its benefits can generate immediate reaction. "You can make the scenario that out of a $100,000 cost, for example, MQL can knock 13 percent off," he said. "That's big money. People look at that real quick."

However, old habits die hard. Unist's Boelkins said people can be reluctant to make a change even though the change could save them money. The right change can be a good thing, though, such as switching to MQL and minimizing coolant-related issues, improving finishes, lowering tool costs, machining faster, eliminating dermatitis, reducing floor space, lowering power draw and improving the environment. CTE

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