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Materials Test Tooling Smarts

Machines Evolve in One Setup Processing

INJECTING INNOVATION

Microhole EDMs Drive Diesel Engine Efficiency

Flexible Automation for Automotive

Auto Manufacturing Focuses on Vision Heads

SME Society of Manufacturing Engineers

Despite having a cab height that exceeds 11′ (3.4 m), this mammoth truck depends on diesel fuel injectors with high-precision micron-size metering holes to operate.

Injecting Innovation

As emissions regulations become ever more challenging, diesel fuel injection systems manufacturers turn to microhole EDM for help

John MacGregor
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There are different forms of electric discharge machining (EDM), but all basically work in the same manner. EDM works by eroding material in the path of electrical discharges that form "a conduction channel" between an electrode tool and a workpiece.

EDM can cut intricate contours or cavities or holes in prehardened steel without the need for heat treatment to soften and reharden the material, which standard machining techniques may require. EDM can process titanium, Hastelloy, Kovar, Inconel and other exotic types of alloys. It can even shape polycrystalline diamond tools. The technology is invaluable for providing machining on parts that may be extremely difficult or even impossible to process using other methods.

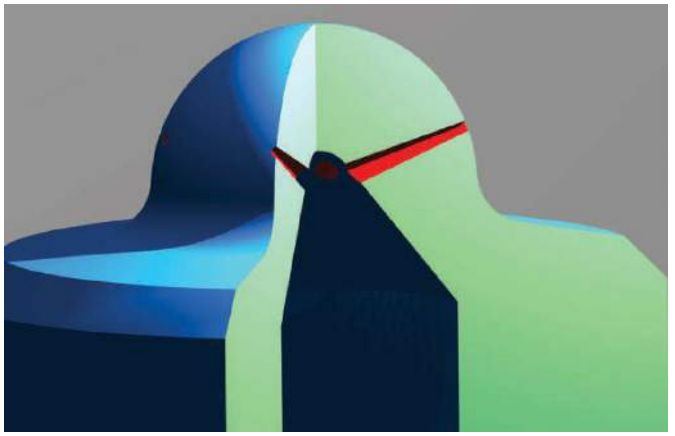

Photo courtesy AA-EDM

Characteristics of typical injector microhole: Size from 0.004 to 0.012" (100–305 µm) diameter; hole tolerance ±0.00005" (1.3 µm); hole depth of 0.40–0.80" (1–2 mm); tapered.

Within the EDM family of machines, there are many standard varieties that perform excellently in a wide range of machining applications. At the far end of this family, however, a small niche services an extremely specific EDM market. These are known as microhole EDM machines. They go beyond the reach of standard EDM, creating burr-free 75–400-µm diam holes in all types of materials.

Many companies manufacture and sell a variety of standard EDM machines. Very few cater to the high-production or specialized applications that microhole EDM addresses. Standard machines such as wire or die-sinkers cut, trace, etch and make medium-to-large holes. Microhole EDM is dedicated only to holes, and only to micron-size precision metering holes, such as those needed for diesel engine fuel injectors.

One reason the standard EDM equipment manufacturers don't go after this niche is that it is too time-consuming and expensive for them to be building "specials" all the time. A large EDM supplier may sell hundreds of machines a year. A microhole EDM manufacturer is quite happy to sell 25 a year. The market is definitely there; it is just not a huge market. But

without the ability to use microhole EDM technology, many products simply could not be manufactured.

Understanding Microhole EDM Technology

Modern microhole EDM applications are highly customized, and manufacturers rarely have only one. To add utility to the technology, manufacturers of microhole EDM machines add additional capabilities: loading/unloading automation, sensing and servo control of the electrode for more precise holes and positioning. Additional tools—laser marking for parts; vision systems for part orientation—are also common. The result is a turnkey machine that is precise, easy to operate, needs minimal attention and is usually highly customized.

Microhole EDM machines can have several types of EDM heads to choose from. Each style is optimized for a specific application. They use brushless DC motor and DSP microprocessors to control the electrode precisely in a super-hard, extremely precise wire guide. Wire guides typically cover a wide range of electrode diameters, eliminating the need to stock a variety of sizes. Five wire guide sizes can cover a range of electrodes from 75 µm up to 400 µm. Life of a high-quality wire guide should be a minimum of 500,000 holes.

Changing a top-line machine from producing one part to another normally just involves selecting the proper part program from the computer screen and loading the correct electrode diameter. There may not be a need to change the wire guide due to their wide-range capability—but if the guide needs to be changed, it can be done in less than 20 minutes. On some machines, one new feature can increase or decrease flow with a press of a button without changing the electrode.

Photo courtesy AA-EDM

High-production automatic microhole EDM machines run untended for eight hours at a major manufacturing facility.

There are two technology camps in the microhole EDM area. One uses multiple EDM heads bolted together and spindles to rotate the electrodes. The other camp designs without spinning electrodes, which can be an advantage in several ways. Things can go wrong with spinning. Any runout of the spindle is disaster when making small holes. Bearings, contamination, complex expensive electrode guides that wear out, and electrode clamps as well as special electrodes all become ongoing problems. Also, heads that are bolted together can't be independently adjusted for hole positions. The machine is locked into making identical parts with all heads.

The machines that do not use rotating spindles are simple to maintain—no balancing or microscopes are required. The multi-head machines typically don't share axes and can make different parts at the same time. Each EDM head has its own axes and they aren't bolted together.

Diesel Industry Overview

One particular part that is a perfect fit for microhole EDM is fuel injectors or any workpiece where there is a need for

fuel-metering holes. For this application the need is to make a precision hole (typically in a multiple hole pattern) for flowing fuel or coolant through a nozzle where it is critical to be able to specify a flow rate.

The challenge in diesel fuel injectors is always ensuring a repeatable, regulated flow rate. It typically takes many microholes and the goal is that those parts keep flow to a very tight, regulated range of ±1.5%. The technology behind this is common in all diesel equipment. You need an optimal fuel pattern to spread the fuel around and above the piston so it ignites quickly, efficiently and cleanly.

One engine manufacturer's parts will be different in size from another's, and even require multiple sizes within its own facility—all needing different fuel injector sizes and designs, so machines must be tailored for each company's production and changeover needs. Computerized part programming makes selecting a change easy, but there still will be times when there is a need to change part clamping or an actual part fixture to fit a different geometry. In a 24/7 type of operation, it all has to be easy to do. Again, this is why there is a need for this specialized equipment. Standard EDM manufacturers simply do not want to get into all of this. Microhole EDM specializes in customers who have singular applications that can't be done by any other method.

The three companies below each have divisions that specialize in manufacturing custom diesel fuel-injector nozzles for either their parent company's engine division or for other diesel-engine related end-customers.

Fuel-Injector Nozzles for Engine Manufacturers

Robert Bosch Fuel Systems's Kentwood, MI, facility makes diesel fuel injectors for on-highway and heavy-duty equipment. Scott Rivette, manufacturing engineer, says that their largest customer is Detroit Diesel for the on-highway type engines. Electro-Motive

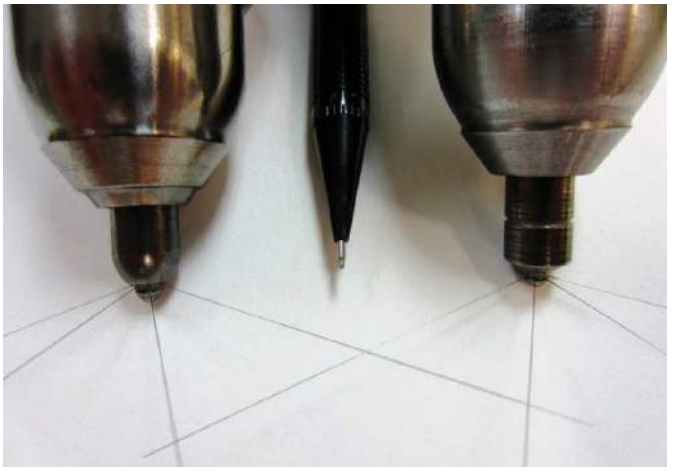

Photo courtesy Robert Bosch

Close up of nozzle end of two injectors. Lines indicate the spray path.

Diesel and Tognum are also key Bosch customers. Many of their products are used for engines in locomotives, ferry boats, mine trucks and equipment.

"We manufacture the nozzle," says Rivette. "That is the very end of the fuel injector. It goes into the combustion chamber. It's what meters the fuel and atomizes the fuel in the engine. It requires a very small hole, on the order of 0.004–0.010" [0.10–0.25 mm]. Typically, there are multiple holes in the nozzle—8, 9 or 10. They have to be very close to the same size and we have to do this on many nozzles at a time. The holes also need to be burr free. I don't want to have to go in and clean them up afterwards."

Bosch Kentwood has been using microhole equipment from AA-EDM (Ann Arbor, MI) since 1999. Bosch started working with AA-EDM because they were faced with a challenge to get nine holes, each with a diameter of 0.004" or less, into a single nozzle. "While the older machines did make micro-range holes, they were not down to this level," explains Rivette. "They were simply not capable. We tried. Since this was a required upgrade so a specific engine would meet new, stricter emissions requirements, we had to find an answer. I found the answer with the new microhole AA-EDM. We now have six machines to help us turn out around 25,000 nozzles a month."

Rivette notes that the biggest benefit in using the new equipment, beside being able to produce that one part, was that the holes were much more repeatable in size across the board. Also, the new technology reduced a lot of operator interface.

"Before I purchased these machines," says Rivette, "we had one person set up to load and unload machines and check parts for quality. Another person worked on the electrical issues, yet another worked on the mechanical issues and one more person did the setups on the machines. The simplicity and ease of use on the new machines means we only need one person.

"They've also introduced a different guide material that guides the wire for the EDM that is far better with a three-times longer life than what we were using. It's a much more flexible concept for changing the electrode sizes. In the

past we would have one guide for each electrode size used. Now we have one guide that covers a range of about 15 different electrodes."

Rivette notes that it is hard to quantify the overall benefits, but just in changeovers he now saves at least five hours of labor. On a day-to-day basis, he estimates labor for running the process has now been cut in half. "I just trained someone to operate our machines," he says, "and it took less than an hour with a totally new operator. On the other equipment it could take days."

Caterpillar Keeps Things In-House

Caterpillar Fuel Systems (Pontiac, IL) makes all the fuel systems for all of the heavy-duty equipment the company manufactures and sells worldwide. Tom Kapraun, purchasing buyer, says that meeting emissions regulations is the biggest challenge all engine manufacturers face today, and precision fuel injectors have a lot to do with compliance.

"Microhole EDM equipment fits into our niche in manufacturing—how we process our parts and how we flow our parts. Hole consistency is primary: No variations are allowable from hole to hole."

Before turning to any sort of EDM, Caterpillar actually drilled the holes. "Microhole EDM is a very small market. We originally found companies that did this technology such as Raycon and Bretco and another called Ann Arbor. Today none of those companies exist. But the gentlemen that are involved in AA-EDM company have all worked in a number of those companies. It is an evolution of all the brains of all those combined companies. We've worked with this whole group of people until they all joined together at AA-EDM and now they are our sole supplier for microhole EDM equipment," Kapraun says.

Kapraun adds that there is no "standard" in his market. There are many different designs. The microhole EDM machines need to be flexible so they can manufacture what is needed at the time. "The difference between a fuel system in a 4000-hp

[2980-kW] power-generation engine versus a 175-hp [130-kW] piece of CAT equipment is a good example of our range. There is a huge difference in the size and configuration of the engines and associated fuel systems. That affects the size of the holes in the fuel injector. It could be either the size or the number. In some cases the size of holes will remain the same, but the number of holes needed will expand. As long as you have consistency in your process it doesn't matter how many holes need to be in any given product. The key is that the piece of equipment first and foremost must retain consistency from hole to hole, and secondly, each hole must be exactly in its specified location.

"Our microhole EDM equipment itself is fully automated, but they are stand-alone," Kapraun notes. "Each piece of equipment is doing it's own thing. It is not part of a line. This is because we process so many different types of components, this approach works best. Operators feed in specific parts or else 'stage' [set up and program] multiple parts and walk away. We run thousands of holes a day in many different parts."

Everything from Mining Equipment to Trains

Cummins Inc. (Columbus, IN) is primarily involved in diesel engines. "Our range is unlimited," Chad Anteau, manufacturing engineering and maintenance leader, says. "We do generator sets all the way from seagoing freight ships and mining equipment to big trains. Our end customers are the engine plants. We ship directly to them and they put our parts into the specific engines."

For most EDM applications, Anteau says that they try to have a machine that is universal so they can run multiple parts across all applications as needed. They look for a simple tooling package so they can easily change over and run new components. That is true for both standard and microhole EDM machines.

"We need both," says Anteau. "We have some EDMs that make large holes and we have the special equipment that makes microholes. Typically anything under 0.010 or 0.008" [0.25 or 0.20 mm] is considered a microhole.

"The performance of a microhole EDM system has to be much higher," Anteau explains. "You're dealing with a much finer controlled spark. You're trying to hold 1 µm of taper versus 25 µm of taper. Therefore the challenge is the very tight tolerances you need to adhere to if you want to become a capable producer.

"When you start talking about microhole EDM there are a lot of things that are critical to the process. One is obviously burrs. EDM is virtually a burr-free technology, but if you don't have the application set up right for the job, anything can happen. If the temperature of your water isn't correct, you'll get what we call recast layers sticking to the part. There are a lot of variables."

Cummins makes many different products for a wide market spread. Anteau says that highway over-the-road engines might be a bit higher volume simply because there are more of them being built than freight trains. The overall market demand generates the volume.

Photo courtesy AA-EDM

Reverse taper machines feature an advanced microhole EDM generator with taper-specific software.

"There are always challenges," Anteau notes. "With new designs it is most often holding the tolerances required, so as we move forward and each design iteration makes the

tolerances tighter, the challenge is, how do you find machine tool builders that can guarantee equipment that can hold those tight tolerances? The AA-EDM equipment can do that and, importantly, it is very flexible to handle multiple applications with quick changeover or no changeover—where you can program parts for changes and different tool sets into one machine for automated changeover.

"Our manufacturing floor space is about 250,000 ft² [23,250 m²] and we have 18 microhole EDM machines working full time," Anteau says. "We've been happy with the equipment. We still have a lot of old equipment, so we can see the difference apples-to-apples right in our plant. The AA-EDM equipment is more capable, much faster and there are many benefits we get from using it."

The Future of Microhole EDM: Keeping Up with Strict Mandates

The biggest issue for microhole EDM equipment manufacturers is keeping up with the needs of the customers as they struggle to keep up with the increasingly strict emissions-control mandates that are issued. Fuel-injection systems are getting more advanced, which often means constantly reduced hole size and placing more holes in close proximity. All must maintain perfect tolerances.

To do this, microhole EDM, like all other electronically-controlled equipment, must continually upgrade performance. As components become obsolete, they must be replaced by the newest technology in microprocessors, chips and circuit configurations. Machines have to stay on top of the latest electronic and sensor technology, not to mention software, which is the bane of every manufacturer using a Windows or similar platform today. Keeping on top of the latest in technology allows the manufacturer to keep building and improving microhole EDM systems and pass those upgrades on to the end users, whether through new machines or by upgrading those already in the field. ME