How Charmilles EDM Made It Possible

The BioInstrumentation Laboratory at the Massachusetts Institute of Technology (MIT), directed by Professor Ian Hunter, creates cutting-edge medical and biological devices. In developing these instruments, the laboratory often requires manufactured components with overall dimensions on the scale of a human hand, and detail on the scale of a hair. Additional requirements for three-dimensional geometry, surface roughness of a few microinches, conductivity, and sufficient strength for biological applications converge to the selection of EDM as the ideal fabrication technology.
A productive partnership between the MIT laboratory and Charmilles US has enabled the manufacture of such challenging devices by EDM. Specifically, the laboratory utilizes Charmilles’ Robofil 1020si wire EDM and Roboform 30 sink EDM as its pre-eminent manufacturing facilities. These machines set the foundation for today’s Robofil 2050 and Roboform 350, which have even more capabilities and a simpler interface. The laboratory has also worked closely with Tony Salvado and Charlie Chachowski of Charmilles’ NJ demo center to push the limits of EDM technology. Harry Moser has also encouraged the partnership with the Laboratory, which is in the Mechanical Engineering Department from which he graduated in 1966.

The Robofil 1020si, launched in 1998, was mainly designed for cutting small, intricate parts using small diameter wire, where accuracy and surface integrity are the priority. This high precision machine has 0.00002” resolution glass scales on all axes, maintaining the same accuracy today as it did when it was brand new. With the “MicroCut” feature standard, it was one of the first, if not the first, to thread 0.002” diameter wire. The “MicroCut” feature also allowed the machine to cut with wire as small as 0.0012”. Today, the FI2050TW has 0.000002” resolution scales (10X better), can accommodate 0.0008” wire, and has the ability to switch automatically from large to small diameter wires. The FI1020si, with travels of X12.52” by Y8.58” by Z10.2” and a maximum workpiece weight of 1100 lbs, has the ability also to cut large parts meticulously or aggressively.

The Roboform 30 diesinker has travels of X13.8” by Y9.8” by Z11.8”. This machine, launched in the late 1990’s, has 0.00004” glass scales standard on all axes, an offline programming system, and a high inertia C-axis with an index resolution of 0.001 degrees that can spin an electrode up to 100 RPM. Today, the Roboform 350 has a more user-friendly interface that definitely does not require an MIT degree to operate, and cuts faster, especially in difficult cutting conditions. Tim Fofonoff and Craig Forest are pushing these tools to their full capability in their cutting edge mechanical engineering doctoral research.

Brain-Machine Interfaces by EDM

The use of wire EDM in fabricating biomedical devices is becoming more prevalent. Tim Fofonoff at the MIT BioInstrumentation Laboratory, fabricates brain microelectrode arrays for...
use in neuroscience as brain-machine interfaces, and wire EDM has become his preferred machining method. In order for a neural prosthesis to reach widespread use, one must be able to manufacture it reliably in an automated fashion. EDM’s use of CNC, allowing for the seamless application of CAD, and its capabilities in generating intricate features with high aspect ratios, make it an ideal choice for this work.

Today, a typical brain microelectrode array assembly consists of about one hundred microelectrodes 1 mm (0.04”) in length, 60 µm (0.0024”) in width, and spaced 500 µm (0.02”) apart in a grid pattern. The microelectrodes are electrically isolated from one another, and are individually connected to recording equipment via cabling or shorter connections to a wireless link. The microelectrodes are insulated electrically, with the exception of exposed conductive regions at each tip. When used for motor studies in mammals, the array assemblies are implanted on the surface of the cerebral cortex, an area known to provide access to motor intent and sensory perception. The microelectrodes protrude about 1 mm (0.04”) into the brain, and record activity from a small collection of individual neurons in the motor cortex. Studies have shown that motion intent of the arm can be anticipated by recording from even a few electrodes. Soon, such devices will be available for restoring neurological functions to patients suffering from stroke, spinal cord injury, and degenerative muscular diseases.

Using Charmilles’ Robofil 1020si wire EDM and Charmilles SW-10-A 100-µm (0.004”) wire, Tim mounts a workpiece perpendicular to the EDM wire and performs two identical cuts, rotating the workpiece 90 degrees between them. He typically runs three low power passes for each cut and has machined arrays from titanium, titanium-aluminum-vanadium alloy, stainless steels, and tungsten carbide,

Schematic of the ultra-high-throughput mutational spectrometer for scanning 10,000 samples of DNA for mutations simultaneously.

Ten-thousand capillaries are arranged in a square array with 1 mm (0.04”) spacing. Four steel constraint plates with square guide holes align the capillaries at their lower and upper ends. The tips of the capillaries are planarized to enable DNA loading and detection.
Although the process should be compatible with most conductive materials, including doped silicon and glassy carbon. Tim often follows this machining by a chemical acid etch, which further reduces the dimensions of the electrodes, as well as primes them for subsequent platinum electroplating. One distinct advantage of using EDM is its ability to cut elaborate shapes into the electrodes in order to aid the later assembly of the brain prosthesis. Tim follows the EDM array fabrication with a multi-step assembly procedure that includes electroplating, epoxying to a micromachined polymer substrate, soldering to a flexible printed circuit board, encapsulating with an insulating polymer, and laser ablating the micro-electrode tips.

By using EDM, one gains the flexibility and repeatability associated with CNC systems. In conjunction with CAD, one can easily explore new electrode geometries and configurations. Tim has used these techniques to produce arrays with vastly differing geometries, including 1141-electrode hexagonal arrays with hexagonal electrodes spaced 250 µm from their neighboring electrodes, machined using three cuts and two rotations, as well as arrays with inter-electrode spacings of less than 250 µm, and lengths exceeding 5 mm. Closer inter-electrode spacings could be obtained by using smaller diameter EDM wire. Batches of electrodes can also be created. For example, Tim has machined forty-nine 100-electrode arrays in a 7x7 grid from titanium alloy using his two cut procedure. These methods are expandable to the development of prostheses for different parts of the brain, nervous system, or eye. More on these methods and this application can be found in the IEEE Transactions on Biomedical Engineering, Vol. 51, No. 6, June 2004.

DNA Mutation Discovery

Craig Forest at the MIT BioInstrumentation Laboratory, is seeking to answer one of the most important questions in biotechnology and genetics today: what are the genetic markers for common diseases? Sorting through the requisite 10^{12} gene fragments to discover these statistically significant correlations between mutation and disease, requires a dramatic increase in throughput over existing technologies. Craig and colleagues at MIT are pioneering an effort to create a 10,000 capillary mutational spectrometer, which will make such a significant endeavor practical by dramatically reducing the time and cost required. The instrument enables parallel loading, separation, detection, and sequestration of DNA mutations from pools of 100 persons per channel, for 10,000 parallel channels simultaneously and continuously. The discovery of the genetic causes for common diseases could lead to simple genetic tests for risk, and to targeted preventative or therapeutic strategies.

DNA mutation separation is performed in a bundle of 10,000 capillaries arranged in a rectangular grid of 100x100. This capillary array is loaded with 10,000 samples simultaneously, using a micro-well array which plugs into the capillaries. The entire capillary array is under thermal control and electrophoretic voltage control for separating mutant from non-mutant DNA. The DNA mutations are detected using an optical detection system, which relies on a light-emitting-diode array for fluorescence excitation, and a CCD camera to image the fluorescence. The instrument utilizes a mutation detection technology called constant denaturing capillary electrophoresis, which is capable of resolving single base differences between fragments of DNA, several hundred bases long, based on the difference in mobility of the fragments in a denaturing environment.

A principal challenge in this undertaking is the fabrication of the 10,000 capillary array. This assembled array permits two orders of magnitude more sample analysis than existing technologies. The 10,000 glass capillaries are held at their ends by respective constraint devices. These devices serve to position and retain the 350 µm (0.014") diameter, 300 mm (12") long capillaries 1 mm (0.04") apart with alignment tolerances of 250 µm (0.01") axially and 25 µm (0.001") radially.

Each constraint device consists of a sandwich of steel, silicone, and steel, and contains an array of thru-holes manufactured by EDM (steel) and CO2 laser micro-machining (silicone). To assemble the capillary array, capillaries are loosely inserted into the 10,000 thru holes in the constraint devices. The devices are then clamped to secure the ends of the capillaries. To fabricate the steel plates, a tellurium copper pin array is first cut on the wire EDM, after selective milling to permit clamping screws. The pins are sized 350 µm x 350 µm (0.014” x 0.014”), spaced 1 mm (0.04”) apart in a square array. The wire EDM job is performed with 0.01” wire in 36 hours, with one part rotation of 90 degrees. The pin array is then used as the tool in the die sink EDM to etch 10,000 square holes simultaneously in hardened 3.5 mm (0.14”) thick 440C stainless steel. An overburn setting of 90 µm (0.0035”) removing an average of 4 mm³/min (0.00024 in³) of steel required 40 hours to etch thru the part.

The assembled array forms the heart of the ultra-high throughput mutational spectrometer, which will uncover the mutational spectra from the entire genomes of 1,000,000 people. This information could help to determine risk of inherited disease, and become a powerful aid in prevention and treatment.