DEVELOPMENT OF A PRECISION, LOW-COST, SMALL FOOTPRINT WIRE ELECTRON DISCHARGE MACHINE (WEDM)

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ABSTRACT
Wire electrical discharge machining (WEDM) is a process that is highly utilized in the manufacturing industry for the cutting of material of any hardness with large aspect ratios. The most common place for its utilization is in the tool and die industry, to create molds and cutting dies very accurately with little or no polishing in the hardened heat treated state. Although it is a widely used process, a cost effective, small footprint, easy to maintain and operate machine, specified with a wide set of operating parameters has yet to be developed. With the increasing trend towards miniaturization and the development of MEMS, a need for WEDM with these characteristics is quickly coming about. This paper outlines the design and building of a prototype, innovative, cost effective, wire electric discharge machine (WEDM).

INTRODUCTION
Historically the corrosive effect of a single electrical discharge was first observed by English scientist, Joseph Priestly in 1770. It was not until 1943 when the soviet scientists B.R. and N.I. Lazarenko developed an RC circuit and control with the characteristics needed to effectively utilize electrical discharges as a material removal process [1]. Although the EDM process has been used for more than 60 years, it is currently not able to accommodate the specific needs of the development and design of micro scale systems.

The WEDM utilizes a traveling wire as the working electrode. The wire, usually 50 to 500 micrometers in diameter is stripped from a spool. It is then guided in a tensioned state between two ceramic or diamond guides, the used wire is then taken up on an additional spool. The wire is constantly moving past each of the guides. WEDM is the most versatile of the EDM processes. Intricate tapered and square geometries can be created with corner radii only slightly larger than half the wire diameter are possible. WEDM also has the capability of cutting parts with very high aspect ratios.

In discussing the prototype WEDM developed here (Figure 1); it will be broken into 3 separate systems, those being the base structure, wire tension system, and finally the power and control system. The base makes up the main structural components which include both the y- and z-axis. The wire tension system is made up of the mounting plate, cross slide, wire pull motor, and wire tension brake. The third and final system is made up of the power RC pulse generator, axis control, and control computer with its user interface.

DESIGN AND CONTROL SYSTEM

Wire Tension System
The first aspect of the design of the WEDM was to determine the basic layout and control components necessary to control both the wire traveling speed as well as the wire tension. The initial design parameter of the wire control system was the ability to tension the wire as low as 1 to 200 Newtons of force with a relative accuracy of +/- 10% of the target tension. Wire tension as low as 1 Newton is required for wires
with diameters of around 20 microns. These specifications are outside of the normal range of commercially available machines, although high precision machines are now being produced that can control wires this small. In most cases the material choice for the wire is brass. Brass is a desirable wire material because of its ability to break down from the physics of the EDM process as opposed to the work piece that is being cut. Brass also has a low ultimate tensile strength (UTS) which means that the maximum tensioning of a brass wire is relatively low.

The machine described here was designed with the ability to accommodate wire made of various materials in a range of diameters. Two additional materials that are used in WEDM machines (as in the case of the material being cut is a semiconductor) are molybdenum, and tungsten. Both of these materials have very high ultimate tensile strengths, which in turn, allow for very high tensions. The other aspect to a wide range of tensions is that as the diameter of the wire decreases, its cross sectional area decreases as an inverse square. As a result, wire with a small diameter requires dramatically reduced tension compared to the same wire with a larger diameter.

Wire speed was also designed with both the ability to travel at a very slow speed to very high traveling speeds (0-250 mm/s). This allows a large amount of variation in control of how much of the wire is eroded away, directly affecting the maximum material removal rate as well as the quality of the surface finish.

The control of the wire tension and speed is made up of a single servo loop. This servo loop includes the wire puller motor with gearbox, line tension sensor, and a constant slip brake. The brake that was chosen was a Magtrol HB-450 hysteresis brake. The torque on the brake is continuously adjustable, resulting in a force on the wire ranging from 0 to 200 N, with unlimited slip. This fully magnetic brake was chosen over the more commonly used magnetic particle brake for its ability to remain very smooth at low rpm's. Magnetic particle brakes, on the other hand, require sufficient rotational speed, as well as heat build up in the particles, to provide smooth consistent torque.

The next component in the servo loop is a Honigmann RFS 150 tension sensor with a range from 0 to 10 N. The tension sensing is based upon readings from a strain gage mounted in the unit. To accommodate the wide range of wire tensions the machine was designed for, it is necessary to alter the wrap angle of the wire around the guide wheel that is attached directly to the sensor. Changing the wire wrap angle from 30 to 180 degrees alters the sensor reading by a factor from 0.5 to 2 times the actual line tension. For the highest tensions a wrap angle of 30 degrees is used and for the lightest tensions a wrap angle of 180 degrees is used. The wrap angle of the wire along with the amount of amplification of the signal from the sensor allows the sensor to achieve the tensions from 1 to 200 Newtons of force within the + -10% accuracy initially specified (see Figure 2).

The complete wire tension system works by first setting the wire puller motor to the desired wire traveling speed. At this point the magnetic brake is set by adjusting the current supplied to the brake which in turn tensions the wire. The wire tension sensor provides the feedback to the servo loop necessary to maintain the correct amount of tension on the wire by adjusting the current to the magnetic brake.
Having selected the necessary components for control of the wire tension system a layout of the components could be designed. One of the design goals, as stated previously, was to maintain a small footprint for the overall machine. Many options on how the wire system could be laid out were explored. Almost all commercially available machines orient the wire in the vertical direction. From that point either the position of the wire can be controlled or the position of the work piece. Both of these methods have their disadvantages. If the wire is to be positioned with respect to the work piece, the problem that arises, in the case of a vertically oriented wire, is that the tank containing the dielectric fluid be designed deep enough to completely submerge the lower wire guide along with the work piece. When designing a system with the wire oriented in such a way, the foot print of the machine, as well as the height of the machine becomes very large. If one were to move the entire tank including the work piece, the problem that arises is that the response time of the wire positioning is affected by the inertia created by moving of the dielectric fluid and work piece set up.

Considering the above arguments it was decided to orient the wire horizontally (Figure 3). By doing so, both of the issues discussed earlier could be eliminated. The result is a simple compact wire tension system that has a constant mass, for positioning reliability, and a dielectric tank that is of minimal volume. In addition, the set up of work pieces is very simple, allowing for a wide range of set up configurations.

All of these characteristics, designed into this innovative prototype WEDM, lend themselves well to the investigation and study of parameters and techniques needed for WEDM to become an effective process for developing MEMS and miniature mechanical systems and the cutting parameters of materials used in developing these systems.

**Base Structure**

The base structure of the machine, which includes the two axes for positioning the wire, was designed around the decisions made for the design of the wire tension system. In order to utilize the horizontally oriented wire, it was necessary to design an axis that could be cantilevered out over the top of the dielectric tank. This made up the configuration of the Y-axis. Mounted on top of the cantilevered Y-axis is the vertical or Z-axis. Both axes are used in unison to provide the two axes that position the wire.

To begin with, the whole machine was mounted to a granite surface plate. In addition to the base being granite, a granite parallel was utilized to raise the horizontal (y-axis) above the top edge of the dielectric tank. Granite was chosen for several reasons including its stability to both temperature changes and vibration, as well as the ability to achieve a very flat surface on which the machine structure could be built.

On the granite parallel are mounted two THK roller profile rails. A plate is mounted to the two bearing rails allowing it to be positioned above the dielectric tank at any position along the tank width. The Y-axis has 300 mm of travel.

The vertical axis structure is then mounted to the horizontal axis plate. The vertical axis motion is enabled by two Schneeberger recirculating roller bearing units. These bearing units allow the wire tensioning system to be position at any depth, from slightly above to slightly below the top edge of the dielectric tank.

Finally the dielectric tank was fabricated from lexan, both for its durability, and that it is clear.
The tank was attached to a tooling plate, which had around its perimeter a tapered drain and a number of threaded holes to aid in the set up of work pieces.

**Control system**

The prototype WEDM is powered and controlled by a modified Optimization Profile 24 control unit that includes a 4-axis PCI motion controller from Galil, an Optimization optoisolation board that handles the IO between the WEDM, and the controller (see Figure 4).

Control of the system is facilitated by the use of Optimization’s Opti rev 1 software and includes servo routines for the tensioning of the EDM wire as well as servo routines for the vertical and horizontal axis that adapt the feed speed to the rate at which material is being removed (Figure 5). This prevents the wire from making physical contact with the work piece and results in the fastest possible machining speed for a given set of EDM parameters.

**CONCLUSIONS**

In conclusion, the prototype precision WEDM that was built and tested, maintained a small foot print (> 1 m³), is cost effective, easy to maintain and operate machine, and specified with a wide set of operating parameters. The many aspects that were considered in the development of this machine led to the successful design of a WEDM that was able to comply with the initial specifications of the development of a prototype wire EDM. The development of this prototype WEDM provides a valuable resource in the study of the WEDM processes to aid in the development of miniaturized systems such as MEMS.

The ability to have complete control over all of the major parameters involved in the WEDM process makes it possible to investigate and develop more efficient strategies in all aspects of WEDM process including, the manufacture of small parts and flexures, investigate and optimize cutting parameters of semiconductor materials, as well as more traditionally processed EDM materials.

**FUTURE WORK**

The dielectric flushing and filtration system will need to be improved to increase cutting efficiency, including more efficient delivery of the fluid to the wire.

**REFERENCES**


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