CHAPTER 1

INTRODUCTION

Electrical Discharge Machining (EDM) is a Non-Conventional Technology that has been known for the last few decades. It is a process widely used in the manufacture of complex shapes and forms in electricity conducting materials. This process is a best one for machining hard materials that are difficult to machine by conventional techniques.

The use of spark erosion as a process for micromachining has also been known for a relatively long period of time (around forty years). However, throughout most of these years, it has remained purely an academic interest while not being implemented commercially. Until recently, most micro EDM’s (μEDM’s) are products specifically built for customers by modifying existing EDM Technologies.

As the demand for miniaturization has increased, the need for micro holes and other micro features in components has also increased. As a result, the need for an accurate yet economical process like μEDM is even more, thus a renewed interest in the technology of μEDM.

1.1 NEED FOR NON-CONVENTIONAL MACHINING

In conventional machining, there is contact between the workpiece and the tool. Parts are produced by removing metal in the form of small chips.
Chip removal can be performed either by cutting tools having distinct cutting edges or by abrasives like silicon carbide, aluminum oxide, and other compounds. Relative motion between the workpiece and the tool is required for cutting of the metal to take place. The workpiece provides the parent metal from which the unwanted metal is removed by the cutting action of the tool to get the required finished shape.

The chip formation occurs due to the shearing phenomenon that results from the contact between the workpiece and the tool, whereas in non-conventional machining, energy in its direct form is utilized (Hassan 2005).

With the development of harder and difficult-to-machine metals and alloys, conventional-edged tool machining has become uneconomical to use due to excessive tool wear. The surface finish and the degree of accuracy resulting are also poor as well. Moreover, a basic requirement of conventional machining processes is that the tool must be harder than the workpiece for removal of material to occur.

On the other hand, non-conventional methods, which utilize energy in its direct form, makes it possible to process materials that were once considered very difficult to machine under normal conditions. These machining methods are classified according to the type of fundamental machining energy used, viz. mechanical, electrochemical, chemical, or thermoelectric. Table 1.1 gives a classification of the different processes used on the basis of the type of energy, mechanism of metal removal, and the source of energy required (Pandey and Shan 1980).
Table 1.1 Classification of non-conventional machining processes
(Pandey and Shan 1980)

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Mechanism of metal removal</th>
<th>Transfer media</th>
<th>Energy source</th>
<th>Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Erosion</td>
<td>High velocity particles</td>
<td>Pneumatic / Hydraulic pressure</td>
<td>AJM, USM, WJM</td>
</tr>
<tr>
<td></td>
<td>Shear</td>
<td>Physical contact</td>
<td>Cutting tool</td>
<td>Conventional machining</td>
</tr>
<tr>
<td>Electrochemical</td>
<td>Ion displacement</td>
<td>Electrolyte</td>
<td>High current</td>
<td>ECM, ECG</td>
</tr>
<tr>
<td>Chemical</td>
<td>Ablative relation</td>
<td>Reactive environment</td>
<td>Corrosive agent</td>
<td>CHM</td>
</tr>
<tr>
<td>Thermo electric</td>
<td>Fusion</td>
<td>Electrons</td>
<td>High voltage</td>
<td>EDM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hot gases</td>
<td>Ionized material</td>
<td>IBM, PAM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radiation</td>
<td>Amplified light</td>
<td>LBM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ion stream</td>
<td>Ionized material</td>
<td>PAM</td>
</tr>
</tbody>
</table>

1.2 MICRO EDM AND ITS USES IN MACHINING

1.2.1 Micromachining

Micromachining is the basic technology used for the production of miniaturized parts and components. ‘Micro-machine’ is the standard term used to refer to very small machines whose size is of the order, millimeter to sub-millimeter. Examples of micro-machines are micro-robots, micro-motors, micro-sensors, capsules inserted into the human body for medical treatment, etc.
The development of such micro-machines has not progressed much due to lack of precision manufacturing processes applicable on the micro level.

Figure 1.1 Process technologies for machining of precision parts and microstructures (Brinksmeier et al 2001)

The machining of precision parts and microstructures can be subdivided into two general types of technologies:

1. Micro system technologies (MST)
2. Micro-engineering technologies (MET)

Microsystems technologies (MST) are used for the manufacture of products for the micro Electro Mechanical Systems (MEMS) and Micro Opto Electro Mechanical Systems (MOEMS). Typical processes used in MST are UV-lithography, silicon micromachining and LIGA.

Micro-engineering technologies (MET) consist of the production of high precision mechanical components, molds and microstructured surfaces. Diamond machining and micro-engraving are the processes used in this field.
Figure 1.1 shows three groups of manufacturing processes. The size of the arrows represents how frequently the processes are used in the two base technologies MST and MET. It is seen that there can be an overlap between the processes, i.e. a combination of the processes can be used for the manufacture of the various precision parts and microstructures.

Figure 1.2 shows the dimensional ranges for the various micromachining methods available.

![Dimensional ranges covered by micromanufacturing](image)

**Figure 1.2** Dimensional ranges covered by micromanufacturing (Dorf and Kusiak 1994)

Using machine tools for micromachining has the advantage of easily machining three-dimensional shapes as these methods essentially copy the tool shape and path on to the workpiece. Though these methods do not have the accuracy that photo-fabrication techniques have, such accuracy in many cases is not actually required. This is especially so since photo-fabrication techniques are predominantly used for features with dimensions less
than a micrometer and with precision range of nanometers. But for components in the milli and micro range, precisions involved are of the order of micrometer and can be provided by machine tools. Table 1.2 shows the different categories of micromachining methods.

### Table 1.2 Categories of micromachining methods

<table>
<thead>
<tr>
<th>Micro machining methods</th>
<th>With tool</th>
<th>With MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid tool</td>
<td>Image tool</td>
<td>Anisotropic process</td>
</tr>
<tr>
<td>Cutting</td>
<td>LBM</td>
<td>Wet etching</td>
</tr>
<tr>
<td>Grinding</td>
<td>EBM</td>
<td>IBM</td>
</tr>
<tr>
<td>Milling</td>
<td>IBM</td>
<td>LIGA</td>
</tr>
<tr>
<td>EDM</td>
<td>etc.,</td>
<td>LBM</td>
</tr>
<tr>
<td>ECM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection etc.,</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mostly the non conventional techniques like EDM, ECM, LBM are used for machining hard, high strength and temperature resistant materials, which are very difficult by conventional machining techniques like milling, grinding, etc…
1.3 PROBLEMS ENCOUNTERED IN MICROHOLE DRILLING

As the dimension of the features reduces, the tolerances for errors also reduce. Therefore, when machining high precision parts, the error should be reduced to a minimum. The factors which cause errors when using machine tools for precision micromachining are:

- Mechanical deformation
- Thermal deformation
- Gap between the tool and workpiece
- Surface integrity
- Coordinate shift in tool handling

Mechanical deformation is common when using conventional techniques like drilling, milling, etc. This problem however, at the micron level, is serious. Since there is no mechanical tool contact in most of the non-conventional machining processes, these techniques are more suited in the micromachining field.

Thermal deformation is dependent on the size of the tool and workpiece and generally poses fewer flaws. But it can be significant when the size of the machine tool increases.

The gap between the tool and the work-piece in non-contact machining processes like EDM can cause errors in the shape produced, thus raising the need for it to be finely controlled.

Coordinate shift occurs when a tool is taken off from one machine and transferred to another machine. Due to errors in clamping or chucking,
the tool may be offset from the actual axis. This result in bias errors, i.e. the whole profile is shifted by an amount equal to the error. So a solution to minimize the tooling is required. The processes like laser beam machining removes the need for tools.

Another problem encountered is in the assembly of the micro-parts, when the parts are taken off, they lose their coordinate information and it is difficult in assembly. A solution to this would be to assemble them on the machine itself so that no bias error or positioning error creeps in.

In addition to the above factors, the production of cutting tools for micromachining is also difficult, making non-conventional techniques an attractive alternative.

1.4 USE OF SPARK EROSION FOR MICRO MACHINING

With advancements in the process of miniaturization, new fields are developing which have a need for micro fabricated components. To meet the demands of such applications like microsurgery, biotechnology, fluidics and high temperature environments, special materials are required. Examples of such applications are fuel injection nozzles for automobiles, miniaturization of medical tools, new advances in medical stents, etc. The need for harder and stronger materials is becoming more and more apparent in present day applications as certain practical problems in machining are faced, such as:

1. Wear of tools as observed for example, in mechanical milling with miniature tools
2. Slow processing speed as seen for example, in focused ion beam (FIB) machining
3. High cost
4. Lack of rigidity of the process

5. Heat generation at the tool-workpiece interface

The µEDM is a feasible alternative that provides the required accuracy as well as economic production capability. In EDM, controlled sparking is used to remove material. This same phenomenon, applied at the micron level, is known as µEDM. Unlike conventional EDM, the energy to be discharged is extremely small since the amount of material to be removed is directly dependent on the amount of energy crossing the discharge gap. µEDM uses a high frequency, low energy spark to remove the workpiece material. The discharge energy must be small enough so that the high surface finish is maintained.

1.5 ADVANTAGES OF µEDM IN MICROMACHINING

The following are some of the features and applications of µEDM in micro-hole machining, which makes it more feasible and a better alternative.

1. It has the ability to machine any conductive material, irrespective of the hardness. It can process materials like silicon and ferrite that have high specific resistance and problems of cracking when processed by ordinary EDM process. Silicon, a widely used semiconductor in the electronics industry as well as in MEMS components, is difficult to machine but can be easily processed by µEDM. Therefore, this ability of µEDM makes it very useful in the manufacture of micro electromechanical systems.

2. A gap is maintained between the tool and the workpiece - making it a non-contact type of machining. Consequently, there is no pressure applied on the surface of the workpiece.
3. It can be applied to minute curved surfaces to form super fine nozzles like those required for fuel injection in automobiles, printing in inkjet printers, as well as for high precision metal masking used in electronic device manufacturing processes like photolithography.

4. High aspect machining can be easily accomplished. It is possible to produce holes with a depth equal to five times the bore diameter. As µEDM is used to prepare dies, which in turn are used for producing micromachines and aspect ratios of 5 to 10 are commonly encountered.

5. High precision and high quality machining is possible through minimization of the discharge energy across the tool and workpiece. Very small burrs are produced – much smaller than those produced by mechanical milling and drilling operations. Thus, this eliminates, or at least reduces greatly, the subsequent deburring operations that would be required otherwise.

1.6 OBJECTIVES OF THE RESEARCH

The objective of the present work is to develop a µEDM setup to produce micro holes on 316L stainless steel and to study the effect of different process parameters, maximize the Material Removal Rate (MRR) and minimize the overcut. In order to attain this objective, the following objectives have been set:

- To design and develop a µEDM setup with sparkgap controller.
• To conduct the experiments for studying the effect of process parameters.

• Prediction of µEDM process performance parameters using multiple regression and Artificial Neural Network (ANN) model.

• Optimization of process parameters.

1.7 ORGANIZATION OF THE THESIS

The thesis of the present work is arranged as follows:

Chapter 1: The Introduction and objectives of the research have been discussed.

Chapter 2: The collection of literatures has been discussed.

Chapter 3: The development of µEDM setup with sparkgap controller is presented.

Chapter 4: The experiments conducted to study the effect of process parameters are reported.

Chapter 5: This chapter provides the prediction of machining parameters using multiple regression and Artificial Neural Network (ANN) modal.

Chapter 6: This chapter provides the optimization of machining parameters.

Chapter 7: The major conclusions derived from the research and the recommendations.
The literature used for the present research is provided in the reference section.

1.8 CONCLUDING REMARKS

In this chapter, the need for conventional machining, µEDM and its uses in machining, problems encountered in micro hole drilling, use of spark erosion for micro machining and advantages of µEDM in micromachining have been discussed. For the manufacture of components with dimensions in the milli to micro range, µEDM is the most feasible solution. The following chapters will discuss the literature related to the area of work, development of the experimental setup, experimental procedures, prediction and optimization of the µEDM setup as it is developed in this research.