INTRODUCTION

EDM as a process was introduced over fifty years ago, improvements in technology have led to increases in both cutting speeds and component precision. Developing from initially toolmaking industry sectors of press tool and mould tools, the EDM process is now mainly found within production engineering, aerospace, motorsport, medical and scientific industries.

Many manufacturing applications for EDM already exist, they are merely waiting to be discovered and implemented. As this happens, the increased use of EDM in manufacturing will continue to grow and diversify though both a combination of awareness and process knowledge.

In manufacturing there will always be a need to find a better way to make something, EDM will help and support the drive to quality cost and delivery.

Knowledge of EDM will provide the ability to design parts that are not possible or cost effective to produce by any other method. The prospect of machining complex shapes in hardened or exotic materials will continue to attract engineers and designers to produce more challenging parts and profiles.

TERMINOLOGY

The EDM industry suffers from a non-standardisation of terminology, which often creates confusion. Electrical Discharge Machining is a generic term for a method of machining that encompasses wire EDM, spark EDM and EDM hole drilling.

SPARK EDM

Spark erosion machines can be also know as vertical, ram, solid or die sinking machines. These types of machines have an electrode mounted in mainly in the Z axis. They are used to remove broken taps, spark cavities into components, produce complex internal spines and gears etc. Modern Spark erosion machines have rotational c axis, multiple electrode positions and even robot loading.

WIRE EDM

Wire erosion machines use a continuously moving wire as the cutting tool. Much like a band saw in principle, the wire (saw blade) feeds from the spool and passes completely trough the work-piece. Although this analogy does not do justice to the accuracy and finishes attainable by wire EDM, this comparison does enable a layman to envisage the concept of wire erosion. The wire is electrically charged and cuts through the work-piece by spark erosion, vaporising and melting the material instead of cutting mechanically like the band saw. Since the wire never physically touches the work-piece, there are no mechanical stresses produced to influence the part of the set-up. Furthermore, wire EDM process produces burr-free machining and provided that the work-piece is electrically conductive its mechanical properties (hardness, toughness, brittleness, and ductility) impose no limitations on the machining process.

EDM HOLE DRILLING

EDM hole drilling machines use around tubular electrodes held in a rotating chuck to spark erode holes. The size range that commercial machines can produce is typically 0.3mm diameter to 3.0mm diameter holes. Special purpose EDM hole drilling machines are available that use non-rotating electrodes and can spark several holes at a time. They are typically used in the aerospace industry for producing cooling holes in turbine blades.

BASIC EDM THEORY

Although the EDM process has been in use for decades, it is still widely mis-understood. EDM is a metal removal process where two electrodes are used to produce a spark, one electrode being the work piece itself, the other being either a formed tool or a wire. The two electrodes should never come into contact with each other. A small gap is maintained between them at all times. The process involves a spark that is generated by a pulsed electrical current being discharged through an insulating dielectric fluid (water or oil) across the very small spark gap between the electrodes. Material is removed by the thermal energy of repetitive sparks. The spark is reported to be in the range of 8,000 to 12,000 degrees Centigrade and it vaporises and melts the work-piece material. The process can be used when the work-piece material is too hard, or the shape or location of the detail cannot easily be conventionally machined. EDM was first implemented over 40 years ago, and used primarily to remove broken taps and drills from expensive parts. The early machines were quite crude in construction with hand-fed electrodes. During World War II, two Russian scientists, B.R. and N.I. Lazarenko, adapted the first servo system to an EDM machine. This offered some semblance of the control that is required for efficient but safe EDM machining today.

Through the years, machines have improved drastically – progressing from RC (resistor capacitance or relaxation circuit) power supplies and vacuum tubes to solid-state transistors with nanosecond pulsing. From hand-fed electrodes to modern CNC machines with controlled simultaneous multi-axes machining. Now with the development of wire EDM the process will revolutionise many industries and change long-standing methods of manufacturing.

THEORY

Assuming that the electrode is positively charged and the work-piece is negatively charged (or vice-versa), the electrode is advanced into the work-piece through an insulating liquid, or dielectric fluid. This is usually hydrocarbon based oil for spark EDM machines, and deionised water for wire EDM machines. The dielectric fluid is integral to the process as it provides insulation against premature discharging, cools the machined area and flushes away the debris.

As the electrode, charged with a high-voltage potential, nears the work-piece, an intense electromagnetic flux is formed and eventually breaks down the insulating properties of the dielectric fluid. Picture the ends of two bar magnets with the north and south poles held apart. If one were to lay a piece of white paper over the magnets and sprinkle fine iron filings onto it, the filings would be caught in the magnetic flux and become aligned.

When the ions in the dielectric obtain polar alignment the resistivity of the fluid is at its lowest. Electrical discharges are able to flow through the ionised “flux tube” and strike the work-piece. The voltage drops as current is produced, and the spark vaporises anything in contact with it, including the dielectric fluid, encasing the spark in the sheath of gasses composed of hydrogen, carbon, and various oxides. The area struck by the spark will be vaporised and melted, resulting in a small crater on the workpiece surface being formed. Due to the heat of the spark and the contaminates being produced by the work-piece, electrode and the dielectric fluid, the flied of ionised particles is disrupted and resistivity increases rapidly. Voltage will rise as resistivity increases and the current will drop, as the dielectric can no longer sustain a stable spark. At this point, the current must be switched off.

During the time current is flowing through the spark gap, the plasma-hot area will rapidly expand away from the heat source- the spark. When the current is switched off, there is no more heat source and the sheath of vapour that was around the spark implodes. It collapse creates a void or vacuum and draws in fresh dielectric fluid to flush away swarf and cool the area. This off period allows the re-ionisation process of the dielectric fluid to be completed and provides favourable conditions for the next spark. The duration of the off-time must be sufficient enough to flush away the spark debris and damaged dielectric, or stability will be difficult to maintain, resulting in arcing or a broken wire. This briefly describes one EDM cycle; it must be repeated over and over again, switching on and off thousands of times per second for successful machining to occur.

The on and off pulses comprise a single cycle of electrical discharge machining. The length and duration of these parameters will depend upon the work-piece material, electrode material, flushing, metal removal rate and the surface finish. Generally speaking, low frequencies are used for rough machining and high frequencies are used for finish machining. Some materials due to density, conductivity and melting temperature must be machined with higher frequencies even during roughing operations (e.g. titanium, carbide, copper.) This will result in improved finishes and surface integrity, but with substantially increased electrode wear. The relationship of the on time to the off time is known as the duty cycle. It is calculated by adding the on-time and the off-time together and dividing this total into the on time. Multiply this quotient by 100 will give the percentage of efficiency, or duty cycle.

Duty cycle = (on-time / (total cycle time)) x 100

Obviously, it would be desirable to reduce the off-time to the smallest possible increment, but many variables such as flushing conditions, electrode material, work-piece material, dielectric condition, etc can drastically affect the ability to maintain concurrent efficiency and stability.

Many of the modern power supplies have the ability to monitor and change conditions and duration of the spark by using adaptive controls. This ability can compensate for marginal cutting conditions automatically allowing unattended operations.

MACHINING PARAMETERS

On and off time are much more than just a switching cycle. They combine with the other basic parameters of the EDM process and effect metal removal rates, surface finish and electrode wear.

ON-TIME

Speed: material is removed during on-time. The spark gap is bridged, current is generated, and work is being accomplished. The longer the spark is sustained (the higher the duty cycle), the more work-piece material will be vaporised.

Finish: consequently, with a longer period of spark duration, the resulting craters will be broader and deeper; therefore, the surface finish will be rougher. Conversely, with shorter spark duration, the finishes will be finer.

Wear: Some times during certain roughing operations using elevated on-times, a phenomenon occurs where every spark leaving the electrode can take a microscopic particle with hit. More sparks produced within the unit of time will produce proportionately more wear, therefore paradoxically; roughing electrodes can last much longer than finisher electrodes.

OFF-TIME

Speed: while metal removal is only accomplished by the spark during the on-time, the duration of rest required for re-ionisation of the dielectric can drastically affect the metal removal rate. The longer the period of rest (or off-time), the longer the job will take. Unfortunately, off-time is a necessity and an integral part of the EDM process, generally the smaller this period of time is, the greater the metal removal rate.

Stability: this is the key to maintaining an efficient metal removal rate. Although increasing the off-time will slow down the process, it can provide the stability required to successfully complete a given EDM application.

Wear: it is sometimes assumed that electrode wear is also factor influenced by off-time. The logic being that by increasing the off-time, the job would take longer and as a consequence the total wear will increase. However, this is not the case because when the current is switched off, it is exactly that – off! Nothing other than the recovery of the dielectric is occurring. No material is being removed, nor any wear occurring. If only the off-time is changed, then the time required to complete the job will also change.

Minimal off-time is a key to machining speed, but unfortunately a sufficient amount of off-time is required to maintain machining stability. Stability is more important than inconsistent speed.

FREQUENCY.

This is the number of times that the current is switched on and off during given period of time, it is usually expressed as a number of cycles per second. For roughing operations, the on-time is usually extended to achieve high metal removal rates and since this will mean fewer cycles per second, it would be described as a low-frequency setting. Finishing operations, with much shorter on and off times, will have many cycles per second and would be considered high frequency. The duty cycle, which is a measure of efficiency, should not be confused with frequency.

The finish left by long on-times is quite rough. This is because the long duration of the spark is sufficient enough to allow a great deal of heat to sink into the work-piece, melting a large crater, rather than vaporising a small one. In addition, the recast layer will be considerably thicker with a potentially deep heat affected zone. This can present problems with the surface integrity of the part although these can be minimised with secondary operations.

Sparks of shorter duration remove little material and much smaller craters are produced. This is the method often used to finish work-pieces and by lowering the power and the on-time an improved surface finish can be obtained. There is also much less potential of thermal damage to the workplace using high frequencies.

CURRENT

This is the amount of power used in EDM, measured in units of amperage. In both spark erosion and wire erosion applications, the maximum amount of amperage is governed by the surface area of the electrode – the greater the amount of surface area, the more amperage that can be applied. High amperage is used in roughing operations and electrodes with large surface areas.

Although electrodes can withstand high amperages, they are seldom used except in instances of large surface areas. While the electrode itself might withstand intense heat that is generated can sink deep into the material surrounding the area being sparked. Also, when using maximum amperages, the spark gap can be quite large, and smaller details may have to be omitted and produced with subsequent electrodes using less power.

The actual spark gap will be determined by the amount of current and the on-time. Usually when elevated currents are applied, an undersized electrode will be used which will leave sufficient material that will be removed later by subsequent finishing operations either using less power and orbiting, or by using finishing electrodes that will have an adjusted spark gap.

POLARITY

In EDM, polarity describes which side of the spark gap is positive or negative. Polarity can effect speed, finish, wear, and machining stability. Spark erosion machines can use both positive and negative polarity, depending upon the particular application, but most operations are performed using a positive electrode. Positive polarity will remove material more slowly than negative polarity, but is most of the time to protect the electrode from excessive wear.

Negative polarity is used for high-speed metal removal when using graphite electrodes, and should be used when machining carbides, titanium, and refractory metals using copper electrodes. Negative electrodes polarity is sometimes used with copper electrodes when no other method is as successful. With graphite electrodes, negative polarity is much faster than positive polarity by as much as 50% or more, but with as much as 30% to 40% electrode wear.

Wire EDM machines almost always run with negative polarity – that is, the wire is negative and the work-piece is positive. As in spark EDM applications, metal removal rates are higher using negative polarity, but since the wire electrode is constantly renewed, electrode wear is not a consideration. However, if the wire is burned deep enough, usually about 20% of its diameter, it can no longer withstand the tension and will break. Increasing the speed of the wire will reduce the severity of the wire erosion and help eliminate wire breakage, at the small expense of increased wire consumption.

THE EDM FINISH