A review of tool electrode designs for sinking EDM process

DR. RAJEEV KUMAR GARG
Department of Industrial and Production Engineering
Dr. B. R. Ambedkar National Institute of Technology
G T Road Bypass, Jalandhar, Punjab
INDIA
gargrk@nitj.ac.in

MR. KULDEEP OJHA
Department of Industrial and Production Engineering
Dr. B. R. Ambedkar National Institute of Technology
G T Road Bypass, Jalandhar, Punjab
INDIA
kojha.gvc@gmail.com

Abstract: - Electrical discharge machining (EDM) is one of the non-traditional machining processes, based on thermoelectric energy between the workpiece and an electrode. In this process, the material is removed electro thermally by a series of successive discrete discharges between electrode and the workpiece. The performance of the process, to a large extent, depends on the material, design and manufacturing method of the electrodes. Electrode design also affects on the cost of electrode. Researchers have explored a number of ways to improve electrode design. The paper reports a review on the research relating to EDM electrode design for improving and optimizing performance measures and reducing time and cost of manufacturing. The final part of the paper discusses these developments and outlines the trends for future research work.

Key-Words: - EDM, electrode, design, MRR, TWR, Multi electrode

1 Introduction
Electrical discharge machining is a non-conventional material removal process widely used to produce dies, punches and moulds, finishing parts for aerospace and automotive industry and surgical components [1]. In EDM process, the electrode shape is mirrored in the workpiece. The electrode dimensions are determined in such a way that spark gap between the surface to be generated and electrode is maintained as shown in Figure 1. Higher gap is required for higher removal rate but also higher gap results in poor surface quality. The performance of the EDM process is highly dependent on the material and the design of the electrodes. The electrode has two parts, i.e. electrode tool and holder. Both these parts are often designed and manufactured into single piece. The simple electrodes are normally manufactured by conventional cutting methods, but complicated shape electrodes may be produced by machining, casting, electroforming or metal spraying. In die-sinking electrical discharge machining process, in general, either fixed electrodes are used to produce die cavities or a rotary device works in conjunction with a CNC to control the electrode’s path in various EDM profiling [2-4]. Manufacturing method of electrode also affects manufacturing time, cost and performance of EDM electrode.

2 Different Aspects of Electrode Design
The prime role of EDM tool is to convey the electrical pulse to allow erosion of work piece with little or no tool wear rate. A lot of effort has gone into the EDM tooling problem regarding inexpensive tool materials, ease of manufacture, rapid work piece erosion, coupled with low tool erosion etc [5, 6]. To improve machining efficiency, roughing, finishing and semi-finishing electrodes are used in EDM process. EDM is mostly employed in
obtaining mould cavities, cylindrical hole machining and 3-dimensional cavity machining. In cylindrical hole machining, through holes and cavities are produced by electrodes of constant cross section. However, in 3-dimensional cavity machining any cavity is machined with one or more electrodes with varying cross section. The tool design procedure is approximately same for both the cases [7]. Ding et al. [8] have discussed basic principles of electrode design. Poluyanov [9] have classified EDM tools depending upon the value of area of projection of electrode on the work piece plane. Two major factors governing the tool design are material selection and electrode wear.

2.1 Material Selection
The selection of the most appropriate electrode material is a key decision in the process plan for any sinking EDM job. The important variables to be considered for selection of electrode material are material removal rate, tool wear rate, surface roughness, machinability and material cost. Properties of different electrode materials and their influence on EDM performance as well as on fabrication of electrodes have been summarized in EDM handbooks [10-12]. Electrode material should have the basic properties like electrical and thermal conductivity, a high melting temperature, low wear rate, and resistance to deformation during machining. However, due to unpredictable nature of EDM process, the basis of material selection is mainly empirical based on experimental data.

2.2 Electrode Wear Rate
The tool wear process is quite similar to the material removal mechanism as the tool and workpiece are considered as a set of electrodes in EDM. EDM electrode wear may be categorized into four types- (a) Volumetric (b) Corner (c) End and (d) Side [7]. Corner wear directly influence shape of the cavity. Heaviest electrode wear occurs at the corners. Jeswani [13] have analyzed the electrode erosion by dimensional analysis. An empirical relation was developed relating the material eroded from tool electrode to the energy pulse, density, thermal conductivity, specific heat and latent heat of vaporization of electrode material. Crokall et al. [14] have explained the effect of debris concentration on erosion rate. They have reported that increased debris resulted in increased erosion. Also use of distilled water as dielectric results in lower erosion rates in comparison to kerosene as dielectric. Mohri et al. [15] have investigated the tool wear mechanism and claimed that tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric on the electrode surface during sparking. They also reported that the rapid wear on the electrode edge was due to the failure of carbon to precipitate at difficult-to-reach regions of the electrode tool. Dauw [15] has developed a geometrical simulation of EDM describing the development of electrode wear and part geometry. It was also considered as an off-line process planning technique as the simulation algorithm is largely based on MRR, TWR and spark gap. However, the simulation of discharge location and spark gap, which are dependent on the distribution of debris concentration, was reported by Kunieda and Kiyohara [17] yielding a more realistic representation of the sparking phenomenon. Kunieda et al. [18] have introduced a reverse simulation of EDM obtaining the shape of the electrode based on the desired workpiece shape. Marafona and Wykes [19] have introduced a wear inhibitor carbon layer on the EDM electrode surface by adjusting the settings of the process parameters prior to normal EDM conditions. Although, the thickness of the layer have made a significant improvement on the tool wear rate but it had little effect on the MRR. Saha [20] has investigated the erosion rates of few work-tool interfaces with similar as well as dissimilar metals. It was found that the distribution of energy per pulse between the electrodes, dielectric and plasma and hence their erosion rates depends on electrode material pair and their polarity.

Minimization and compensation of electrode wear has always been one of the major motives in electrode design process. Researchers have proposed several methods for compensating electrode wear in EDM. Orbiting of the electrode relative to the workpiece is the most common machining strategy proposed by researchers for compensating the tool wear. It involves the electrode tool making a planetary motion producing an effective flushing action, thus improving part accuracy and process efficiency [21].

3 Innovative Tool Electrode Designs
Generally 3-D form tools are employed in EDM process which are found costly, take more time for their manufacturing and associated with high wear rate particularly when subjected to cutting of complex shapes [22, 23]. Therefore researchers have investigated many innovative electrode designs summarized in following subsections.

3.1 Plate, Frame and Ball Ended Cylindrical Tool Designs
Plate type tools can only be applied with basic shapes (spheres, conics and simple 2D sweeps) and intermediate shapes (complex 2D sweeps, ruled surfaces and fillets). When applied for complex shaped deep cavities, plate tools results in poor dielectric flow
causing the debris to accumulate and be suspended in the gap. With simple plate tooling, however, good flushing conditions can be achieved even in the most difficult circumstances [24]. The application of plate type tools results in high MRR, high relative electrode wear, good dimensional accuracy and better surface finish.

Application of frame type tool in EDM is a novel technique for generation of linear, circular and curved contours without using any complex shaped electrodes. Bayramoglu and Duffill [25] have discussed the brief advantages of using frame type tools. Compared to form type tools, frame type tools are easy to produce and inexpensive. With application of frame type tool, the machining time reduces considerably. In EDM process surface finish depends upon generator setting and tool surface area [26]. Smaller machining surface results in better surface finish. The total machining area of frame type tool is smaller than for 3D form tool. Therefore application of frame type tool results in better surface finish. Also, catering for dimensional changes in frame type tools could be carried out under NC control rather than employing different tools for roughing, semi finishing and finishing operations as in case of 3D form tool. Therefore, frame type tools are less expensive. Like plate type tools, frame type tools are only suitable for basic shapes (spheres, conics and simple 2D sweeps) and intermediate shapes (complex 2D sweeps, ruled surfaces and fillets). Yu et al. [27] have presented a new method, called uniform wear method, for 3D micro-EDM. Simple electrodes such as with round or rectangular section were applied. Uniform wear at the end of the electrode was realized by layer-by-layer machining. This maintained the original electrode shape and converted the three dimensional electrode wear to a linear one. By compensating the linear electrode wear, complicated three dimensional cavities were successfully machined. This technique was developed for micromolds, but the applicability for normal size molds was also confirmed.

Like 3D form tools, ball ended cylindrical tools can be employed for producing basic (spheres, conics and simple 2D sweeps) and intermediate (complex 2D sweeps, ruled surfaces and fillets) sculptured (CAD obtainable shapes, higher order polynomials) and general (3D implied shapes indicated on drawings). Standard cylinder or ball ended cylinder as the tool electrode is employed in contour or CNC EDM machining technology [28, 29]. Ding and Jiang [28] have studied special requirements on tool paths demanded by contour EDM machining and have proposed a two-phase tool path generation method for 4-axis contour EDM rough milling with a cylindrical electrode. In the first phase of the method, initial tool paths for virtual 3-axis milling were generated in a commercial CAD/CAM system—Unigraphics, which provides users with plenty of options in choosing suitable tool path patterns. From these tool paths, cutter contact points between electrode and workpiece are reversely calculated. In the second phase, considering the special requirements of EDM, which include discharging gap compensation, electrode wear compensation, DC arcing prevention, etc., the electrode was adjusted to an optimized interference-free orientation by rotating it around the cutter contact points obtained in the previous phase. This new orientation together with the reference point of electrode is output as new tool path. The whole algorithm has been integrated into unigraphics, machining simulations and tests have been conducted for 4-axis contour EDM rough machining. Being a special application of conventional EDM, contour or CNC EDM machining of free-form surfaces is a new technology emerged in recent years. Due to its special machining properties, although the electrode moves in the same way as a cutter in mechanical milling, tool paths generated for milling cannot be used directly in contour EDM machining. Discharge gap compensation, electrode wear compensation and many other factors have to be considered in the tool path generation process. Chang and Hong [29] have investigated a buffered digital differential analyzer algorithm in a computerized numerical controller performs milling electric discharge machining of a curve constructed from a sequence of segments using a traditional computer-aided manufacturing system. The proposed algorithm interpolates more than one segment in a sampling interval and supports the effective machining of a parametric curve when the electrode crosses the connection between the short segments. The accuracy of the speed and the trajectory of motion were ensured without the time function of the parameter specified by two terms of a Taylor expansion, such as in a real-time parametric curve interpolator. The proposed algorithm is compared with the reference–word interpolation and real-time polynomial interpolation used in a milling EDM to confirm improvements of erosion speed. After the parametric curve has been converted into the segments using a fixed parameter increment under constrained chord error and the memory size, the buffered digital differential analyzer algorithm interpolates more than one segment using a simple digital differential analyzer in the main program during an interruption interval. The algorithm selects appropriate commands in interrupt service routine after the results obtained by the digital differential analyzer have been pushed into the memory, to ensure that the computation time of the interrupt service routine is short. The algorithm guarantees the accuracy of the line-connected contour and the speed without using real-time polynomial interpolation. The actual chord error can be
3.2 Multi-Spark and Multi-Electrode Tool Design

The Kunieda and Muto [38] proposed the multi-spark EDM method which was newly developed to obtain higher removal rates and lower energy consumption compared with conventional EDM. This technique is a modification of the basic EDM principle because in basic EDM, only single discharge is delivered for each electrical pulse. To set up multiple discharge points for each pulse two types of electrode design have been proposed by researchers. Mohri et al. [39] divided a tool electrode into multiple electrically insulated electrodes connected to the pulse generator through a resistor. In this case, after a discharge occurs in the gap between one of the divided electrodes and the work piece, the gap voltages at other electrodes are maintained at the open circuit voltage level for a certain period of time until the surface electric charge over these electrodes is redistributed or another discharge occurs. Therefore, finally discharge can occur at different electrodes simultaneously. Suzuki et al. [40] and Kubota et al. [41] proposed a twin electrode discharge system for the electric discharge dressing of metal bonded grinding wheels. The discharge circuit was formed by connecting the pulse generator to one of the two twin electrodes, the grinding wheel, and the other twin electrode serially. In this system, for each pulse, two discharge points can be obtained simultaneously at both the gaps between the twin electrodes and the grinding wheel using only one pulse generator. Kunieda and Muto [38] used twin electrode discharge system. The removal rate and energy efficiency were found higher than those of conventional EDM in which there is only one discharge point for each pulse.

3.3 Computer Assisted Electrode Design

Ding et al. [8] have introduced a computer-aided EDM electrode design system for die and mould manufacturing. Under this system, when electrode boundaries are selected, the electrode tool, tool holder and a work coordinate system are created automatically. Thus, by this system, electrode tools and its holders can be created automatically from workpiece design. This design system also generates a workpiece co-ordinate system for machining purpose. The system has been tested and proved to be able to shorten electrode design lead time significantly. The proposed method begins with the detection of the uncut region in the mould insert that requires machining. The boundary of the region is then obtained and projected onto the plane that is perpendicular to the EDM direction (X-Y Plane). The trimming and extension of the boundary curves are invoked when necessary for ensuring that the projected boundary forms a close loop. After that, the close-loop boundary is extruded along the Z direction to create a solid that contains the region that requires the EDM process. Subtraction of the part geometry from the extruded solid gives the solid model of the electrode. Although the electrode created by Ding’s method has the correct shape to perform the EDM process for the uncut region in the part, the electrode may itself contain uncut regions. In such cases, the single electrode has to be split into multiple electrodes to avoid machinability problem of the single electrode. This process is tedious and requires an experienced engineer to ensure proper splitting.

Mahajan et al. [42] proposed the basic principles of designing knowledge based system for automated EDM electrode design. This system works by taking into account, the logic that an experienced EDM specialist would use to design electrodes. First the overall methodology to design EDM electrodes automatically is described on the highest level then the details of this methodology are explained followed by conclusions. The success of this system depends to some extent to the radius detection software algorithm. However, these rules are presented using high-level description, and automating the electrode design process with them would be a difficult task, which has not been addressed in this research work.

3.4 Some More Innovative Designs

Kadir Dursun and Can Cogun [43] have investigated the performance of electrodes formed by using copper wire...
bunches (WBEs). WBEs are proved to be economical as compared to conventional solid electrode. The use of WBE electrode for rough machining decreases machining cost and time. It decreases both the number of electrodes required and delay in starting machining due to preparation of electrode. Shibayama and Kunieda [44] have described improvement of machining characteristics of EDM of deep slots using a tool electrode which has micro holes for jetting dielectric liquid over the working surface. The electrode was made by the diffusion bonding of two copper plates, over an interface on which micro grooves for jetting the dielectric fluid were formed using electrolyte jet machining. Use of the newly developed tool electrode was found to shorten the processing time and improve machining accuracy significantly compared with the conventional solid electrode. Since the holes are micro in size, the outlet shapes are not replicated onto the bottom surface of the slot machined.

4 Remarks and Future Trends

- Like material removal mechanism, electrode wear mechanism (ERM) is also a complex phenomenon. Simplified assumptions and approaches in theoretical modeling, have led to large disagreement with results. Therefore, there is no sound theoretical basis for selecting a suitable tool material and design for a work material. Selection of suitable work-tool interface is mainly based on empirical results.

- Application of plate, frame and ball ended cylindrical tool design seems to have a lot of potential for commercial applications. Their applications depend upon exploitation of CNC EMD capabilities allowing servo controlled tool movement along four axes. However, market survey shows that these capabilities are not fully being exploited by tool makers. The reason for the same needs to be explored and thoroughly investigated.

- Multi spark EDM and multi electrode EDM are relatively new techniques for MRR improvement and are still under experimental stage. More empirical validation using different workpiece materials is required before the method is recommended for commercial applications.

- There is negligible published work available on comparative study of various electrode designs and electrodes manufactured by different techniques with same/different work materials. So, there is a lot of scope for future research work in this field.

- Researchers have investigated innovative ways of EDM electrode manufacturing using wire bunch electrodes, electrodes with micro holes etc. However, there is limited published literature regarding performance of such electrodes. Such electrodes should be investigated thoroughly for many possible work material-electrode material combinations before their commercial application.

References:


