Invited paper

NOVEL ELECTRODE DESIGN METHOD FOR ORBITING ELECTRICAL DISCHARGE MACHINING

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Abstract

Orbiting electrical discharge machining (EDM) introduces additional electrode motion to enhance debris removal mechanism during machining process. This method offers static EDM superior machining quality due to advancement of debris removal. However, designers often encounter design difficulties of electrodes used for orbiting purposes. There is no CAD package that currently supports geometry adjustment for orbiting motion of EDM process on the market. Therefore, designers perform manual electrode compensation for orbital motions. Manual compensation is considered as a big challenge for parts with intricate geometry, is prone to human-error, and consumes huge amount of design time. This research aims to facilitate those difficulties encountered using the principle of inverse Minkowski sum. A detail explanation about electrode design steps and its validation is presented in the paper. This algorithm is integrated and developed in commercial CAD system as an intelligent tool to automate the electrode design process.

Keywords: CAD, Design, Electrode, EDM, Orbiting

Introduction

Current manufacturing processes entangle CNC milling operation and electrical discharge machining (EDM) to produce parts of intricate geometry. Considering the significant improvement in material hardness, parts made from hard materials, so that they sometimes cannot be formed using milling tools efficiently. EDM is commonly employed in the area where high-precision cavities and molds have to be formed, e.g. in the production of aerospace components, medical appliances, automotive parts, and so forth. This process is frequently used to generate intricate or fine shapes that cannot be machined through conventional milling. Although current high speed milling (HSM) technology has greatly improved and can be applied to wide machining areas, there are still other areas where EDM excels the manufacturing of specialized components or hard materials. For parts with unique geometry, making a special milling tool is inefficient and costly. Producing EDM electrodes is more plausible than making special cutting tools since EDM electrodes can be made from soft materials, e.g. copper alloys or graphite, which are easy to machine with less production cost. Such examples are few areas that are not feasible by traditional machining.

The advancement of material hardness often make EDM as the first option since utilization of milling tools is constrained by material's hardness. However, EDM possesses low machining efficiency due to excess electrode wear and low material removal rate (MRR). Electrode wear is partly caused by poor mechanism of debris removal from EDM working gap, is also caused by improper selection of electrode material or machining parameters. Orbiting or planetary movement is one of EDM methods used to improve machining efficiency through enhancement of debris removal [1]. In this technique, the electrode moves along a controlled cycle pattern, hence generates more space and extra pumping action to easily remove debris from the working gap. Figure 1 shows the movement of the electrode during orbiting EDM and Figure 2 shows comparison of debris distribution during static and orbiting EDM.

Orbiting provides a consistent surface finish and even wear, and maintains perfect round geometry or sharp details depending on the orbiting cycle pattern [2]. Despite efficiency improvement caused by orbiting application, designing electrode for a selected orbiting cycle pattern is somehow complicated. The challenge of electrode design arises as the electrode has to be simultaneously adjusted for discharge gap and orbiting motion. Manual design has been applied to electrode design process. However, manual design is more prone to failure when the required shape has complex geometry [3]. Therefore, most designers prefer to design the electrodes which are covering only a small and simple area of the required shape and do separate machining to form the whole shape. Even though this technique prolongs machining time, it avoids machining inaccuracy due to incorrect electrode shape [4]. Also, Manual design heavily relies on designer's knowledge of orbiting effect to the final geometry of spark machining.

This study aims to facilitate those difficulties encountered on the electrode design of orbiting EDM. A novel method is proposed to simultaneously compensate both discharge gap and orbiting motion in order to produce accurate electrode geometry based on a chosen orbit cycle pattern. The compensation strategy is well-formulated and integrated with commercial CAD system to automate electrode design process. This strategy also covers electrode validation to confirm the effectiveness of the produced electrode for forming a part which agrees a blueprint. Several mold models have been successfully processed with the developed method.

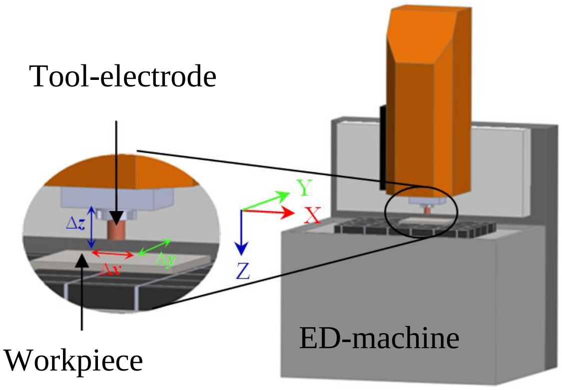


Figure 1. Tool movement in orbiting EDM

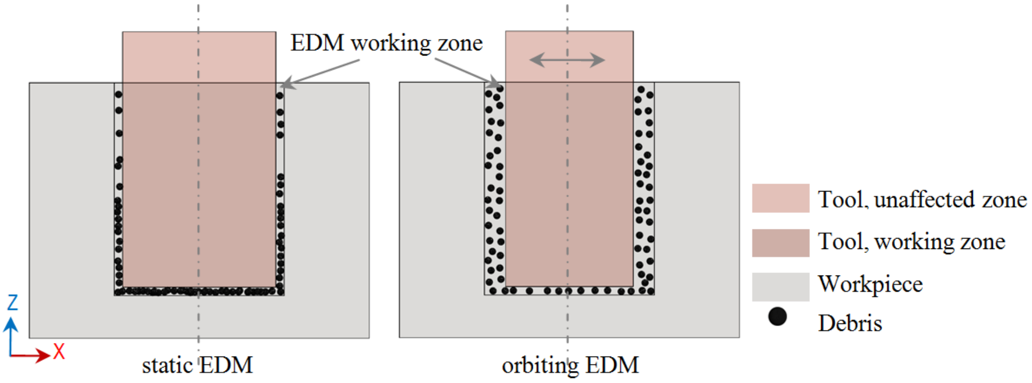


Figure 2. Comparison of debris distribution in EDM working zone

Methodology

Generally, EDM utilizes several processes for roughing and finishing. Thus, mold production time becomes incredibly long to get the whole shape done. Orbiting EDM can efficiently generate high quality surfaces with fewer electrodes in comparison with static EDM, hence subsequent finishing process is sometimes omitted in orbiting EDM. In the design of static EDM electrodes, the shape of electrode is obtained by taking the reverse shape of required part minus a thin layer of machining overcut caused by discharging on all EDM surfaces. The overcut or discharge gap which is uniformly applied throughout the electrode surfaces is defined from a specific combination of machining parameters. Hence, electrode design can be done by subtracting a constant thickness of discharge gap from the reverse shape of design shape. During machining, orbiting introduces additional electrode movement which cycles in a controlled movement to a pre-determined machining depth. Therefore, electrodes designed for orbiting purposes have to consider the chosen orbit motion into the final geometry of electrode, otherwise the final product dimensions will deviate from the blueprint [5].

Only few shapes like cylinders or cuboids that can be uniformly compensated for the orbiting motion yields accurate results for orbiting EDM process. Figure 3 shows electrode samples generated by uniform offset and the respective product geometry for three different shapes. The product model shown in Figure 3(a) is formed by the circle orbiting pattern, and the product models shown in Figures 3(b) and (c) are formed by the square orbiting pattern. In these results, Figure 3(a) and Figure 3(b) confirm identical dimensions between the design model and the product model generated by orbiting EDM with the uniform offset electrode. However, as shown in Figure 3(c), the uniform offset failed to produce exact dimensions. The product generated by orbiting EDM with the uniform offset electrode has different dimensions on all corners. Uniform offset application is valid only for straight edges and circles, not for corner radii or slanted edges.

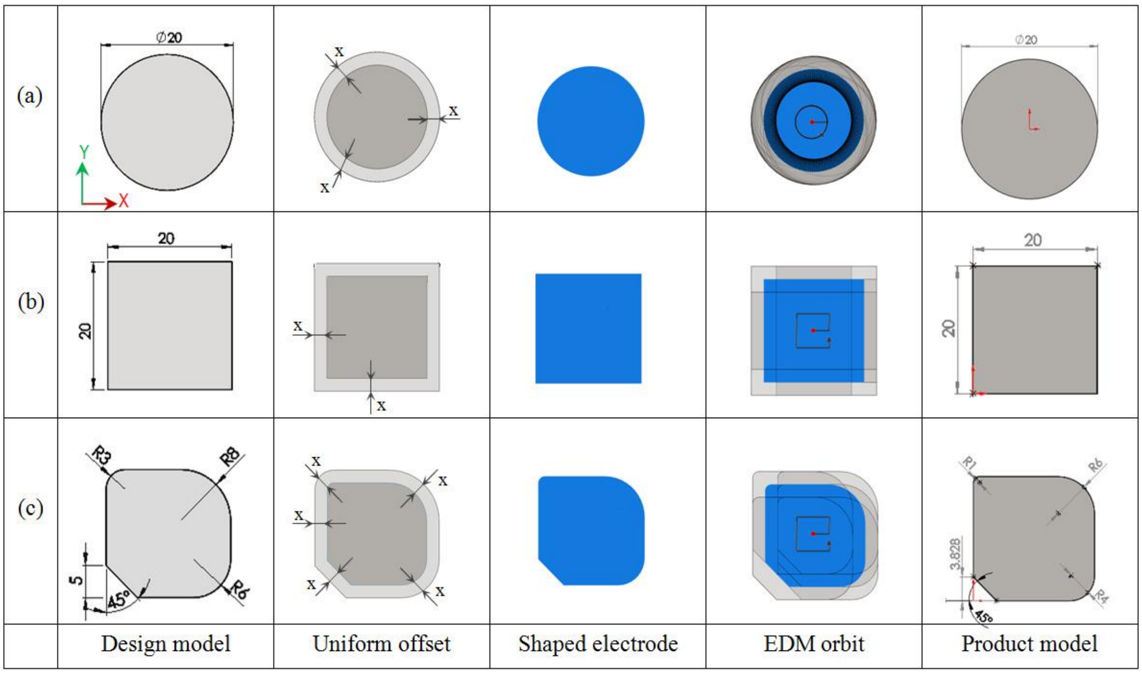
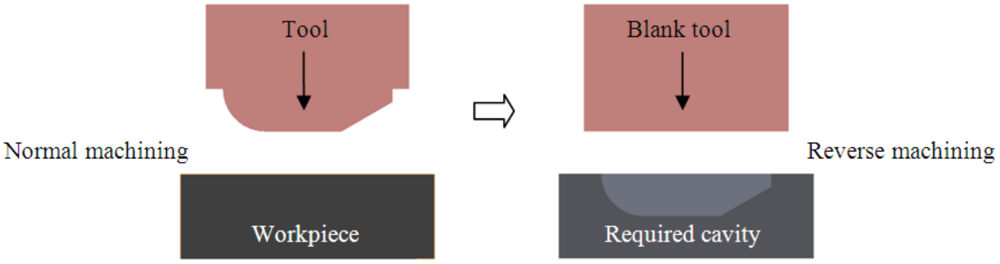


Figure 3. Samples of uniform offset electrode and its effect to the product geometry by orbiting method

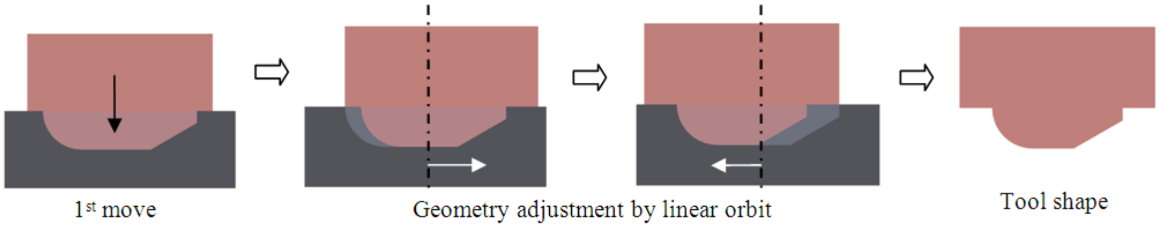
Electrode Design Principle

Electrical discharge machining is done by removing most of the materials on the positively charged material, generally the workpiece, and only a few on the negatively charged material, commonly the tool electrode. In normal ED-machining, the workpiece is the part to be shaped, hence the tool-electrode need to have the reverse shape of the required cavity to be imprinted next on the workpiece, as depicted in Figure 4(a). However, in the tool making process, to generate the shape of the tool electrode for a desired geometry, Kunieda et. al [6] reversed the EDM process to obtain the shape of the electrode based on through simulation of ED-machining. This is possible in real machining by reversing the machining polarity on ED-machine so that most of removal occurs on the tool-electrode instead of the workpiece, provided that the workpiece has the required cavity carved on it.

The proposed tool adjustment processes for the applied orbit path are shown in Figure 4 (b). First, the blank tool is fed down to adopt the shape of the required geometry. In this figure, the tool is adjusted for linear orbit motion. To do the adjustment, the required geometry part (the bottom part) is moved according to linear orbit. Thus, the tool volumes are removed according to the respective orbit movement, and the tool shape that has been adjusted for the linear orbit motion is generated.



(a) Normal ED-machining and the reverse process



(b) Toolmaking processes for orbiting EDM with linear orbit

Figure 4. EDM process: normal and reverse

This process is similar to the inverse principle of Minkowski sum. Minkowski sum has been widely implemented in the fundamental operations of geometric objects, such as robot motion planning and generating tool path for NC operation. To obtain the correct electrode shape for a particular orbit path, this work utilizes the inverse Minkowski sum principle to shape the electrode.

Principally, Minkowski sum uses two shapes: A and B, as two point sets in E_n, and the Minkowski sum can be defined in the set theory as:

$$A \oplus B = \bigcup_{b \in B} A_b \tag{1}$$

where U denotes the set union operators and A_b indicates that the set of A is being translated by b. Electrode design utilizes inverse Minkowski sum to obtain the shape of electrode. Conversely, inverse Minkowski sum can be defined as decomposition of A by B. It can be regarded as deletion of some member of point set A by the second point set B as defined in Equation (2):

$$A \ominus B = \bigcap_{b \in B} A_b \tag{2}$$

EDM electrode is obtained by deleting some volumes of design shape by swept volumes of orbit cycle, following the principle of Equation 2. If the required design shape is defined as S, orbit cycle as O, a blank set of shape as X, and electrode shape as E, then E can be obtained by:

$$E = X \ominus S_o \tag{3}$$

In Equation (3), S_o is the modification of design shape S by orbit cycle O. If an orbit cycle has n vertices of $\{o_1, o_2, \ldots, o_n\}$ to make a full cycle, then S_o is formed by adding those vertices' set to design shape S by:

$$S_o = \bigcup_{n \in O} S_n = S_{o_1} \cup S_{o_2} \cup \ldots \cup S_{o_n} \tag{4}$$

Equation (3) states that the electrode shape E is taken from the difference between S_o and X, or it can be defined as:

$$E = X \setminus S_o = \{ y \mid y \in X \text{ and } y \notin S_o \} \tag{5}$$

Equation (4) and (5) is used as the formulas to define the electrode shape for a chosen orbit cycle.

Electrode Validation

The equation to derive electrode shape for a particular orbit cycle has been formulated in Equation (5). However, the electrode shape has to be confirmed for its validity for orbit operation. To do so, Minkowski sum principle is used to validate Eq. (5) following:

$$S' = E \oplus E_o \tag{6}$$

where S' is the product shape which should have the same point set as designed shape S, and E_o is the modification of electrode by the chosen orbit cycle O. E_o is defined by:

$$E_o = \bigcup_{n \in O} E_n = E_{o_1} \cup E_{o_2} \cup \ldots \cup E_{o_n} \tag{7}$$

with E_n is the n^{th} modification of electrode point set by n orbit vertices of $\{o_1, o_2, \ldots, o_n\}$. The created electrode is valid when the member point set of design shape S equal to the member point set of product shape S' created by Equation (6). The electrode shape is false otherwise.

It is surely difficult to observe validity of the electrode shape by comparing point sets of S and S'. It is easier to compare the point sets of S and S' from their geometrical point of view. Therefore, this work elaborates electrode design and validation method in a geometry basis by integrating the algorithm into a CAD system.

Automation of Electrode Design

The proposed method is integrated in a CAD system to simplify electrode design process for orbiting EDM and to make a convenience of a CAM system. Electrode design in a CAD system requires several steps to execute it. First, a three-dimensional design model is constructed in a CAD system. The design model is a blueprint whose dimensions have to be followed by a product generated at the end of design process. Next, a designer selects an orbit cycle pattern to be used for processing the model. Figure 5 shows two- and three-dimensional orbit cycle patterns that are commonly used in industry. It should be noted that each cycle pattern has the different starting point but it mostly starts from the center. Also, each motion has different orbit vertices depending on the cycle pattern. A designer should define the orbit coordinates for the selected cycle pattern and the length of orbit to specify extraction of each point of the electrode surface.

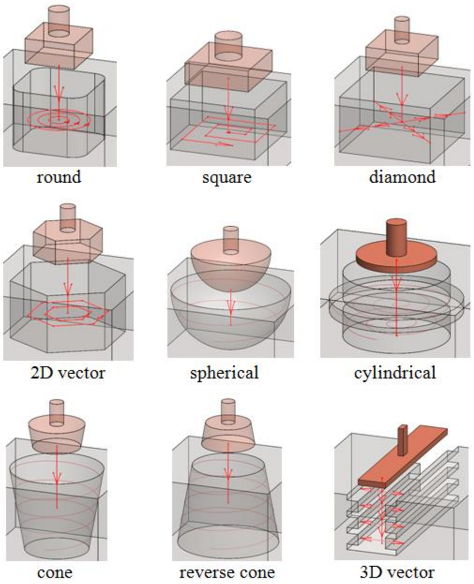


Figure 5. Typical two- and three-dimensional orbiting

An example of designing the electrode for a part with the diamond orbit cycle pattern as illustrated in Figure 6 is described. The diamond cycle pattern is an X-like pattern with each arm length equals to the diagonal length of orbit gap. The model is copied and translated to each discrete point with a small moving distance in orbiting coordinates until the orbiting position reaches the first coordinate. As a result, several solid bodies whose number depends on the selected cycle pattern will be copied in a CAD system. These solid bodies are combined into one body which is the Minkowski sum. To obtain the EDM electrode for this model, a blank solid body is extruded through the combined body, and a Boolean subtraction of the combined body from the blank solid body is performed. A new body which is the shape of electrode adjusted for the chosen orbit cycle pattern is obtained from this operation. Figure 6 illustrates an application example of this method to determine the electrode shape for the diamond orbit pattern in order to machine a mold of brake disk of a train part.

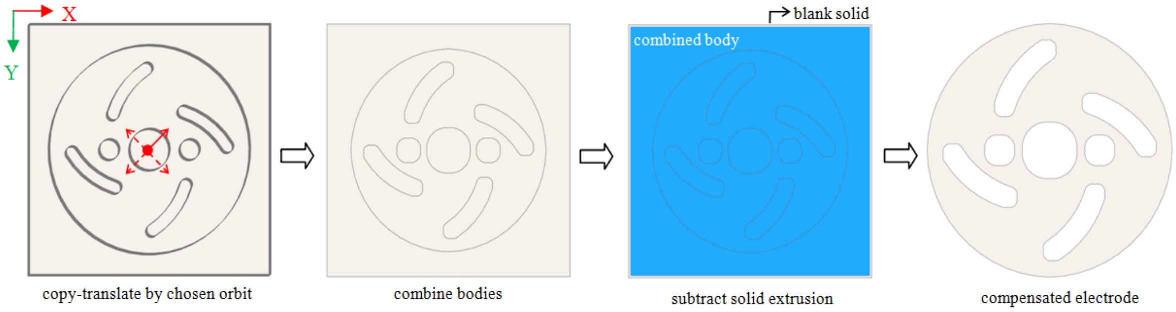


Figure 6. Steps to compensate for orbit motion

The compensated electrode presented in Figure 6 has not been compensated for orbiting, yet. To do so, a thin layer is extracted uniformly from EDM working surfaces. EDM working surfaces are generally all faces except the face which hold the electrode holder. The extraction thickness equals to the overcut value. Figure 7 shows the result of overcut extraction from the processed electrode. This is the last step of electrode design, which yields a physical electrode design for orbiting EDM.

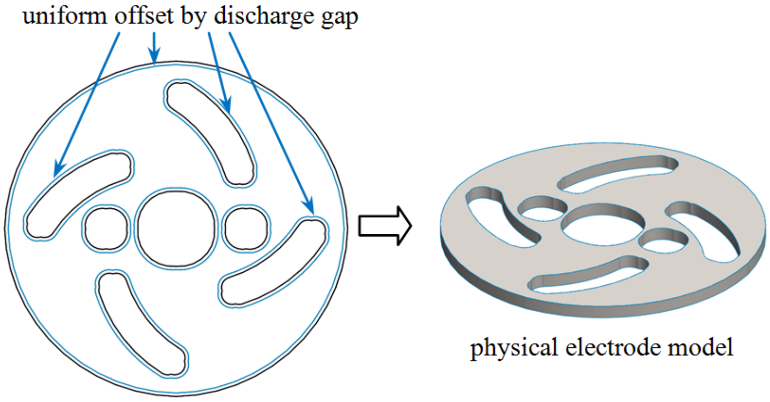


Figure 7. Extraction of discharge gap to generate the physical electrode model

All of design steps explained in this section is developed and automated as an additional package inside a CAD system (SolidWorks) through the use of its Application Programming Interface (API). The API provides hundreds of functions which allow a direct access to SolidWorks operations. The package application was written in Microsoft Visual Basic for Application (Microsoft VBA). In this work, all the tasks required for electrode design are coded in Microsoft VBA and are called directly from a user interface. The interface contains commands, menus, and buttons that are linked to the written code. This application is easy to use for inputting basic information of the CAD model and the chosen orbit. It does not need to have a deep knowledge about orbiting process to design an electrode. Using it is a real saving time since all required steps are automated. The automation also reduces errors caused by manual design operations, particularly for models with complex shapes. Figure 8 shows screenshot images of electrode design process using the package developed in the CAD system for a mold.

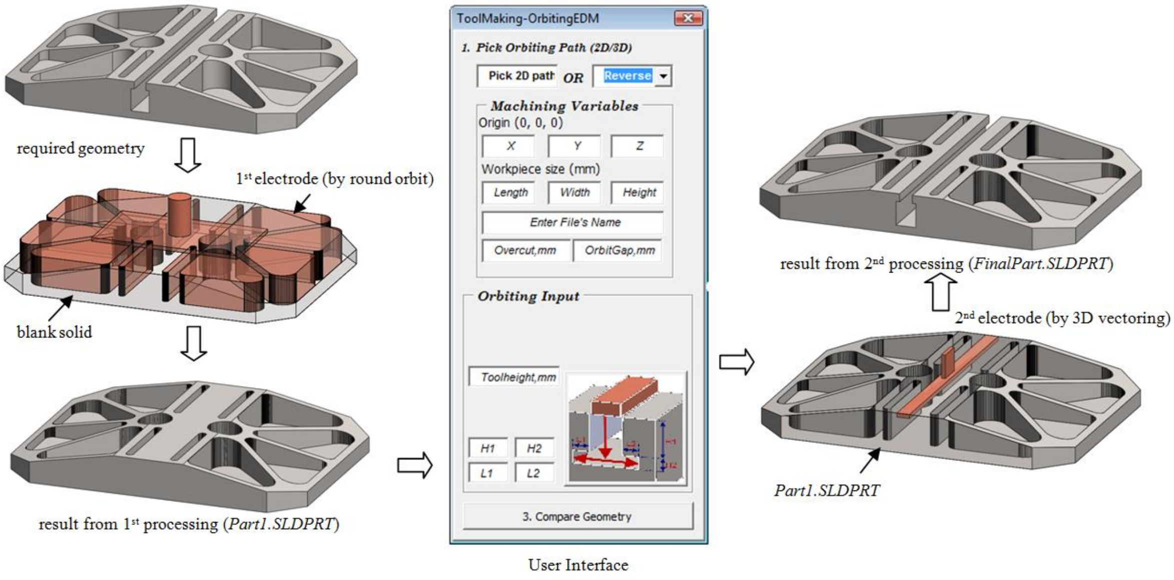


Figure 8. Screenshot images for mold which requires two orbiting passes

The electrode to machine the mold by orbiting EDM is designed in the two processes; the first process is executed with round orbiting and the second one is processed with 3D orbiting. The user interface shown in Figure 8 has three input sections. The first section is for machining variables, the second section is for orbiting parameters, and the last section is for electrode validation. The validation is done by comparing the product geometry and the blueprint (required geometry). The design lead time to execute the two processes is less than one hour. Manual electrode design generally takes up around 10% to 20% of total mold production time, which is around 200 working hours for intermediate mold with medium level of complexity [7]. Integration and automation of electrode design in a CAD system provides convenience as well as a significant reduction of design lead time and reduce errors due to manual design process.

Case Study

Automotive parts require precision and mostly have complex details. Figure 9 shows two mold models of auto-parts with complex geometry. The first model is a vehicle gaiter mold and the second model is a mold for one part of a transmission system kit. The electrodes for both molds were designed for orbiting EDM using the round cycle pattern. The round orbit is preferred since both molds contain many circular shapes and fillet. Even though round cycle pattern requires longer time in design process due to its vertices number, round orbit still warrants precision for processing circular shapes. In this work, round motion is built from 72 vertices to generate a smooth round orbit, which means that the copy and translation process explained in section 3 was repeated 72 times with different vertices coordinates' value. Table 1 presents performance of manual electrode design and automation electrode design using the developed package application.

It can be observed from Table 1 that automation of electrode design significantly saves design lead time by reducing the number of mouse-clicks and computer processing time. The modification column in the automation section is meant for manual user intervention that has to be made during design process, i.e. selecting faces to compensate for orbiting

need of electrode design package for orbiting EDM purposes. The intelligent tool is able to design electrode directly from a CAD model and validate the customized electrode for the chosen orbit cycle pattern with minimum user interventions.

A significant improvement on electrode design lead time and computer processing time is observed through the use of the developed CAD package. Electrode design automation is capable of compensating both non-uniform offset characteristic of orbit motion and uniform offset characteristic of discharge gap successfully, which has been the biggest challenge for designers when combining them in manual mode. The automation also reduces human errors when facing a concurrent compensation of discharge gap and EDM orbit for a complex geometry. Furthermore, the integration of the developed automation design algorithm with a commercial CAD system makes an effortless design transfer for subsequent fabrication process of the electrode.

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