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Optimum electrode path generation for EDM manufacturing of aerospace components

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ABSTRACT

Nowadays the trend of using monolithic parts on aerospace industry has suffered a considerable increase due to the benefits they provide. However, their complex shape and the low machinability of the materials used to manufacture them make their manufacturing by conventional methods difficult or even impossible. Electro discharge machining is an alternative to manufacture this kind of parts. Existing solutions do not offer a generic method that guarantees the smoothness of the erosion path, independently of the workpiece geometry and "user-dependent" features. With the aim to solve the problem, a new objective function has been proposed and a hybrid optimization method (*Genetic Algorithm*+*Trust Region Reflective* method) has been implemented. Results obtained by a single variable problem show that the proposed objective function generates a smooth path regardless of machined shape and available degrees of freedom. Therefore, the implemented optimization method combines a low computational cost together with the obtaining of the largest possible electrode. The optimized algorithm has been applied to an industrial case-study, the erosion of a shrouded blisk, to check its adequacy. The lack of instabilities during the erosion of the part proves the best performance of the developed work.

1. Introduction

The increase of the use of monolithic parts in the aerospace industry, such as blisks (bladed integrated disks), aimed at the improvement of the efficiency of aircraft engines, is a strong trend nowadays [1]. A blisk consists of a part which combines both blades and disk on a single piece, eliminating the joint between them, which is the main source of cracks. This feature provides some extra benefits, such as higher turbine efficiency, lower aerodynamic resistance and lower weight. Other turbine parts with similar characteristic are the impellers.

However, the manufacturing of these parts presents some difficulties. Materials most commonly used are titanium alloys and nickel or cobalt based superalloys, which are heat-resistant materials [2]. They are also resistant to oxidation and corrosion but their main disadvantage is their poor machinability. For this reason, the manufacturing of these parts using high-speed machining is complex and it presents high tool costs and long process times [3]. Besides, in the case of shrouded blisk, in which vanes are confined between an inner and an outer disk, the access of the milling tools to the cavity can be difficult or even impossible. Other alternatives are electro-chemical machining (ECM) or lost-wax casting. However, casting cannot achieve the required integrity for this kind of pieces.

Electrical discharge machining (EDM) is a feasible alternative for the manufacturing of this kind of parts [4,5]. Due to the nature of the process, there exists no contact between tool and workpiece, which means that the mechanical properties of the material do not have influence on the erosion process. Therefore, it can be used to machine materials with low machinability and high hardness values. Moreover, since there is no contact, there are no machining forces, which helps improving accuracy. Klocke et al. [4,5] performed a cost-analysis and concluded that the EDM process is a competitive alternative for the manufacturing of Ni-based blisks.

Traditionally, surface integrity obtained by EDM has been questioned. The main reason for this is that part of the eroded material is not actually removed and re-solidifies on the surface, creating a layer which has different properties than base material. The characteristics of this layer depend on the type of EDM process (wEDM or sEDM), the process parameters, the material of

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Nomenclature

v_{px}, v_{py}, v_{pz} translation degrees of freedom (x, y and z axis) of the part
$v_{p\theta x}$, $v_{p\theta y}$, $v_{p\theta z}$ rotation degrees of freedom (around x, y and z axis) of the part
v_{ex}, v_{ey}, v_{ez} translation degrees of freedom (x, y and z axis) of the electrode
$v_{e\theta x}$, $v_{e\theta y}$, $v_{e\theta z}$ rotation degrees of freedom (around x, y and z axis) of the electrode
R 3D Rotation matrix
R_x rotation matrix around x axis
R_y rotation matrix around y axis
R_z rotation matrix around z axis
e_x, e_y, e_z coordinates (x, y and z) of each point of the electrode
p_x, p_y, p_z coordinates (x, y and z) of each point of the part
d_k distance between electrode and cavity
I current intensity
V voltage
t_i pulse on time
t_0 pulse off time
S servo voltage

electrode and part or the dielectric fluid used [6]. The problem of this material volume is that it is a potential source of cracks. But in recent years some authors [7] have worked on eliminating this problem, making the machines more competent and adjusting erosion parameters in order to reduce and even remove the recast layer. Such improvements are leading the EDM process towards new frontiers in the manufacturing of aircraft components.

In the case of blisk manufacturing, two of the challenges for the EDM processes are electrode design and the definition of the optimum tool path to erode the cavity.

Some authors have developed equipment to erode this kind of parts using 5-axis EDM [8]. However, they have not provided any information about electrode design and machining strategy. Traditionally, those tasks have been carried out “manually”, and have strongly relied on designer's experience.

Li et al. [9–11] tackled the problem of electrode path calculation. The proposed electrode path calculation algorithm starts with the electrode in its final position and a monotonically increasing (or decreasing) degree of freedom is chosen. In each step the electrode is moved a defined distance (or angle) Δ in the mentioned degree of freedom, and after that movement the values of the rest of the degrees of freedom need to be calculated. To find the optimal combination of values of those degrees of freedom, an objective function able to evaluate the “quality” of different combinations of translations and/or rotations is defined and minimized via an optimization method. In the case that electrode geometry does not allow an interference free path, the electrode is modified reducing its size.

A gradient based optimization method (SQP method) is used in the above cited-works in order to minimize the proposed objective function. In general, optimization methods are divided into two main groups: gradient based methods and heuristic methods. Gradient based methods calculate the optimum point of the function using function's first derivate (gradient) and second derivate (hessian). They begin with an initial point and find the closest solution following a search direction defined by gradient and/or hessian information [12]. The main disadvantage of gradient based methods is their lack of guarantee to obtain global convergence. If the initial point is close to a local minimum instead of a global minimum, the function could get stuck at that local minimum and not reach the best solution. Another significant drawback is the amount of evaluations needed to find a solution, which can increase computational cost and can result on a slower algorithm. Heuristic methods [13], which usually are an alternative to gradient based methods, use a different type of algorithms to obtain an approximation to the optimum value. These methods do not need function gradient (or hessian) information, so they lack advantage of knowing a search direction. In order to increase efficiency, optimization methods can be combined using the so-called hybrid methods [14]. These methods combine a heuristic optimization approach to explore a bigger region of points and then a gradient-based optimization method which refines the previously obtained value.

As shown above, a solution to the problem of path generation can be found in [9–11]. However, electrode trajectory provided by this method is not the most appropriate due to its lack of smoothness. The stability of the solution largely affects erosion times and process performance, which are critical issues when it comes to the actual industrial application of the EDM process to blisk manufacturing.

In order to obtain a more smooth path, researchers of the same group developed an electrode design method and a feed path planning method called *tangent tracking* [15,16]. They show that the generated path by Li's method [9–11] contains “jumps” that can affect the stability of the process. Liu et al. have proposed their method as a solution of this problem. The method consists of adjusting the initial electrode form to the profile of the cavity and searching its path by coinciding the tangent vector of the electrode center curve with the tangent vector of the flow channel in each step. A smooth feed path can be obtained which helps in reducing the number of electrodes and machining time [15,16]. However, their technique does not guarantee the optimum result, because there is not an optimization process involved in the solution of the problem. The method to obtain the center curve consists of joining the center points of sections made on the flow channel. Nevertheless, it is not specified how they generate these sections and the obtained path highly depends on the way the channel is sectioned. Besides, the EDM machine user may want to define the available degrees of freedom (*dof*), but if the electrode must follow the center curve of the flow channel, a given number of specific *dof* will be required by this method, which may not fit machine characteristics.

For these reasons, the general method proposed by Li et al. [9–11] is considered more appropriate, since it does not depend on the cavity shape nor on an user dependent center curve. A further contribution to the above-acknowledged works is presented in this paper. The definition of the objective function and the smoothness of the generated path have been identified as fundamental topics that have not been addressed yet. A complete proposal for electrode path generation, including these topics, is described in Section 2 of this work. It has to be emphasized that the proposed method is generic for all kind of parts and it can be used regardless of the cavity geometry. Once the method has been proposed, practical validation is shown in Section 3 trough an industrial case-study, which involves the application to the EDM of a shrouded blisk. Finally, the main conclusions drawn from the present work are summarized.

2. Method for optimum electrode path generation

The main contribution of the present work is the definition of an objective function (see Section 2.2), for its use in the erosion