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Experimental measurement of wire-lag effect and its relation with signal classification on Wire EDM

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Abstract

Wire deformation and vibration are classical topics of WEDM research. Many high-added value components (aerospace, medical, automotive…) benefit from the very tight tolerances that can be achieved by using wire EDM. However, there are some particular conditions in which the required accuracy is not fulfilled, as in the case of low-radius circles cuts. An important example of this could be found in the well-known fir-tree form geometries.

In this paper, direct measuring of the influence of wire deformation on part geometry is proposed. Classical methods presented in literature are optical or are based on measuring wire-lag using electrical contact between wire and workpiece. The idea that the effect of wire deformation can be directly measured by suddenly stopping the machine is developed in this contribution. Using this approach, the effect of wire deformation can be measured even when cutting circular paths of small radius. A complete set of experimental tests is presented under different WEDM cutting conditions; including the effect of low dielectric pressure, part radius and part thickness. Analysis of discharge patterns has also been carried out, so that the lack of accuracy in WEDM'ed parts can be correlated with the quality of discharges. Results show that wire deformation increases as much as 45% when cutting a circular interpolation of radius 0.8mm if compared with a straight cut on a part of similar thickness. This fact has direct implications on the error caused by the tractrix effect when cutting small circular paths. Likewise, the relation between wire-lag and discharge type percentages (based ionization time) stablishes that, as the radius increases the percentage of discharges without ionization time raises, decreasing the one that has an ionization time above 10μs.

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Keywords: WEDM; precision; wire-lag; radii; free-form; discharge classification.

1. Introduction

Wire deformation and vibration are classical topics of WEDM research. Many high-added value components benefit from the very tight tolerances that can be achieved by using wire EDM. High-added value sectors such as aerospace, medical, automotive, etc. benefit from the increased performance of WEDM in terms of accuracy [1]. In the manufacturing of Low Pressure Turbines (LPT), WEDM has gained attention for cutting disc turbines (fir-tree geometries) as an alternative to broaching [2]. In this case, there is also concern for fatigue life of WEDM'ed components [3, 4].

Accuracy is critical in the case of the above-mentioned fir-tree geometry, which is characterized by continuous changes in path curvature with small radius. Disc turbines also exhibit in many cases, taper cutting. Finally, the operation cannot always be carried out with the highest dielectric pressure. Due to a limited access to the cutting zone, in many cases nozzles cannot be adjusted to part surfaces and the available dielectric pressure decreases, limiting thus cutting performance and accuracy.

The causes for wire vibration are well-known and have been thoroughly studied by important researchers during the last decades. Among others, very interesting explanations on

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the nature of the causes and phenomena that govern wire vibration can be found in the works of [5-7], and more recently, by Chen et al. [8].

Kinoshita [9] visualized wire vibration within a deformation envelope, which is useful to understand the effects of vibration on part accuracy. Many authors have used the concept of wire-lag to explain lack of accuracy when cutting low-radius circles and corner cutting. Sarkar [10] proposed a novel method to estimate wire-lag. Using this concept, several strategies have been proposed to improve accuracy, i.e. on-line monitoring, deviation measurement and corrections considering that wire can be described featuring a parabolic deflection [11]. Later, Hsue et al. [12] generated special paths depending on Material Removal Rate (MRR) in corners in order to avoid this error; while in [13] geometrical inaccuracy was analyzed taking into account most relevant variables, such as average cutting speed, surface finish characteristic and geometrical inaccuracy caused due to wire-lag. Limitation of cutting speed during corner cutting has also been analyzed in [14]. In a recent work [15] it is described how the trajectory of wire center can be fitted to an elliptic theoretical model.

Modern WEDM generators allow a very strict control of each individual discharge. Different WEDM discharges exhibit different performance in terms of removal capacity and effect on wire vibration. Analysis of WEDM process using high frequency oscilloscopes is mandatory nowadays if deep knowledge is to be gained. Caggiano et al. [16] presented a very interesting research work on WEDM discharge classification. On these bases, in a recent work the authors have developed a signal feature extraction system to detect the presence of marks on the WEDM'ed surfaces [17].

Following the State-of-the-Art, in this work an experimental research on the actual effects of wire vibration on part accuracy and its correlation with discharge patterns is discussed. In Section 2.1 the methodology for direct measuring the effect of wire vibration on the cut surfaces is defined. The methodology involves suddenly stopping wire movement, so that its shape can be recorded on the channel. Once the method for measurement has been presented, a complete set of experimental tests is described (Section 2.2) and the results obtained are discussed (Section 3).

Variables present in industrial practice when cutting fir-tree geometries are taken into account in the experiments, namely path radius, part thickness and dielectric pressure. Discharge patterns have been recorded and the discharges have been classified in terms of ionization time, as proposed by Caggiano [17]. Previously, other authors had taken into account this criterion, such as the classification of Watanabe [18] or the importance that Puri et al. [13] gave to this variable.

It must be highlighted that the objective of the work is not to study the influence of WEDM parameters on wire-lag. In fact, commercial WEDM technology provided by the machine manufacturer is used. However, when using this technology, variations in ionization time are noticed, and this is the effect to be addressed in this study.

The relation between wire vibration and its trajectory has direct implications on the error caused by the tractrix effect when cutting small circular paths. Conclusions of this study will be useful to develop specific WEDM strategies for cutting high-precision parts.

2. Proposal of method for measuring the effect of wire vibration on part geometry

2.1. Experimental method

In the following paragraphs the method to measure the effect of wire deformation on the machined part will be presented. The method involves cutting sample parts and suddenly stopping the machine during the cutting process. Figures 1.a and 1.b represent the erosion process for straight and circular paths. As described by the figures, discharge process is halted inside the part, and then, a new cut (dotted line) perpendicular to the previous one is carried out in order to extract the sample where wire shape was printed. This allows access to both components of wire deformation [18]: on the plane that contains the direction of the movement and the wire itself (*wle*); and on the plane that contains a vector perpendicular to direction of movement and the wire itself (*ce*).

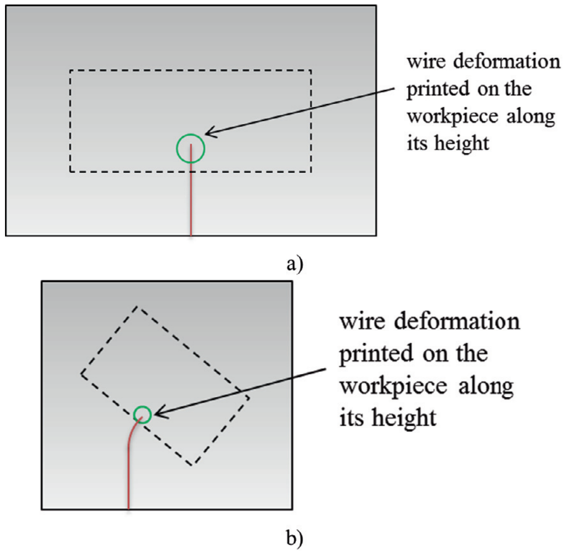

Fig. 1. Example of workpiece geometry employed for *wle* measurement in a: a) straight cut; b) circular interpolation.

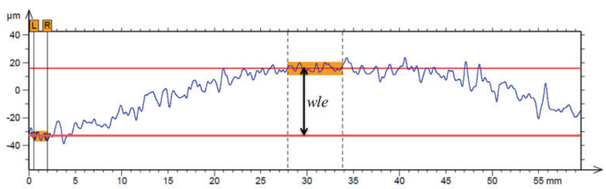

Fig. 2. Example of *wle* measurement in a straight cut. Workpiece height is 60mm.