Discussion on Thin WEDM Error Analysis and Characterisation

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Abstract

The analysis of WEDM is still nowadays an important field of research due to the difficulties to measure the process characteristics: narrow gap (~10 mm), dirty environment (oil or deionised water), high frequency (>100 kHz), etc. Nevertheless, the WEDM technology has been improved thanks to the theoretical and empirical results of different research groups that have made use of state of the art technologies to measure temperature distributions, displacements, frequencies or electrical signals for spark characterisation. The accurate measurement of machined parts has also brought light to the machining process, being this aspect critical for the improvement of the EDM technology.

In the last years, the growing tendency to miniaturisation has promoted the research of production techniques capable to produce small components with very high precision. EDM technology, due to the low processing forces, was immediately identified as one applicable technology for the production of moulds and dies. The technological research in the field has been very important, reducing the minimum wire diameter from Ø0.1 mm to Ø0.02 mm, the machine components have evolved to provide a finer control of all process parameters, specially the wire traction force, the machine feed and the spark energy. Thanks to the research in WEDM, nowadays it is known that, during the process, electrostatic, electrodynamic, electromagnetic, dielectric and wire traction forces act on the wire. Many of these forces push and pull the part from the workpiece. The result of all these forces acting on the wire is an error of the machined shape that, in normal WEDM, is of only a few microns (3~20 mm depending on part height). This error is specially important when machining flat walls and machining corners in which the feeding direction change.

Despite using lower energy values, due to the origin of the different forces acting on the wire and the low tensile strength of wires smaller than Ø0.1 mm (considered as thin wires), the errors that can be found in miniature parts and microparts are bigger than the corresponding values in conventional WEDM. The present paper analyses the errors that appear when applying thin wire EDM ( Ø0.03 mm) to the machining of 3 mm height components made of tungsten carbide, it presents the difficulties that are found when trying to characterise the errors in small components. A possible error analysis approach is presented and then the errors are discussed.

Keywords: thin wire WEDM, metrology, error characterisation

1. Introduction

The present paper presents the current research that is being conducted by the Department of Micro & Nanotechnologies of Tekniker and the Department of Mechanics of the Engineering University of Bilbao in order to characterise the machining errors that appear in the machining of precision miniaturised parts by thin-wire electro discharge machining (WEDM).

When machining small components with machining direction changes using Ø0.03 mm wire by WEDM in aluminium or steel, some deviations can be observed between the programmed path and the obtained part dimensions. These deviations appear also in conventional WEDM and it has been studied by different authors [1,2,3], being very important the contribution of the Engineering University of Bilbao to the study of this topic [4]. One solution to reduce this error, despite being time and resources consuming, is the application of trim cuts. In any case, the number of trim cuts to apply and the process variables to apply in the different cuts depend on the material and the component height. The analysis of the error should drive to conclusions about the way to reduce the number of cuts and improve the component quality.

The analysis of previously machined parts has shown that the real error presents an important scattering that depends on many aspects, specially on the type of wire, the wire tension, etc. The measurement of the error itself is another important issue, the tool that is being applied is Ø0.03 mm diameter (a cutting width close to Ø0.039 mm depending on the material and the process parameters if the gap is considered) and the errors can be as big as 2 μm, being the error-to-tool ratio much larger than the equivalent relation in conventional machining.

Finally, the maximum part height that can be machined by thin WEDM in different materials is very important in order to establish the maximum dimensions of the components that can be processed by this technology. The identification of the limit is complex because it depends not only on the wire, but on the process parameters as well.

2. Conditions and Objectives

The test have been performed in the machine available at the Micro and Nanotechnologies Dep. of Tekniker: Sodick AP200L. The dielectric fluid used for the thin WEDM process was IonoPlus 3000 from Oel-Held (the application of oil as cutting fluid can reduce the gap and reduce the unit removal rate of the EDM process).

The thin WEDM process depends as much on the machine as it depends on the auxiliary tools like the contact pieces, the guides or, specially, the used wire electrode [5,6].
Most of the mentioned components are currently provided by the machine tool manufacturers, being the field of selection reduced to a narrow range of products. The thin wire electrode is provided by a limited number of manufacturers. The materials that are applied for the manufacturing of the electrodes is tungsten (Sumitomo, Intech, Primatec, etc.), molybdenum (Sumitomo, Intech, Primatec, etc.) or brass covered steel (Bedra). The material has a big influence on the maximum applicable wire tension and the obtained accuracy. One of the advantages of the tungsten wire is its higher stiffness with respect to the rest of applied materials, it makes it more suitable for manual threading.

The wire electrode used in the tests was supplied by Intech. It was a Ø0.030 mm tungsten wire with a tensile strength bigger than 2200 N/mm².

The tests pursued to obtain information about the following concepts:
- Maximum expected error when changing the cutting direction
- Tension to apply on the wire for different part widths.
- Error to Width ratio identification

3. Description of the Tests

The tests have been performed by Tekniker with the support of the Engineering University of Bilbao. The University has performed a important research in the field of conventional sinking EDM and WEDM. The approach to the analysis of the thin WEDM process has taken benefit from the experience of the partners in order to define the testing procedure. The procedure defined by the Engineering University of Bilbao in previous projects[4] has been applied to this study trying to suit all parts and facilities to the thin WEDM process.

The concepts and variables fixed at the beginning of the study are presented in the next lines.

3.1 Part Material

Thin WEDM process is a quite recent process, lacking the documentation of the conventional process. Nevertheless, the machining of some materials are documented by the machine tool manufacturers and by some other authors, existing technology tables for steel and tungsten carbide (WC).

The first tests were performed using WC. Tekniker has a wide experience in the machining of this material that provides very good results for the machining of small parts.

The material homogeneity and the width of the raw material were carefully controlled: small plates of ISO P10 grade WC and 3.2 mm±3 µm width were used.

3.2 Part Dimensions

The test parts should present some easily identifiable direction change in the machining path. The selected direction change was 90°, it is quite common to perform such direction changes and the error is easier to characterise, for close angles (<45°), the WEDM process presents important distortions and instabilities that make the analysis more difficult. These cases may be studied in latter phases of the research.

In order to force the machine to interpolate two axes in the direction change and fine the effect of the wire lag, a 0.050 mm radius round was applied at the corner to force the machine to interpolate the axes during the direction change (fig. 1).

Concerning the part characterisation, it should be considered when designing the test parts. The measurement of small components is nowadays an important topic of research (micrometrcology) that has found many problems. Knowing this difficulty, the possible characterising equipment was analysed in order to state if the part could be measured conveniently.

Normal WEDM test parts are measured using optical microscopes or coordinate measuring machines (CMM) presenting errors that depend strongly on the part height and the machined material. For thin WEDM, the tool is much smaller and the width is also reduced. The conventional CMM probes are usually too big (Ø>0.2 mm) to characterise miniaturised components and optical microscopy provides a resolution that is in the same order of magnitude of the error that must be measured (±1~2 µm). Other techniques that are being applied to measure and characterise microcomponents, like SEM or AFM, present limitations in order to measure depth or measuring area. Finally the confocal microscopy turned out to be a reasonable alternative, it could reconstruct the 3D geometry of the test parts if the correct dimensions were applied.
The part dimensions were adjusted to the measuring area of the white-light confocal microscope available at the facilities of Tekniker (693.50 x 509.18 µm). The stitching phenomena presents some errors in the joining area and they were avoided.

In order to analyse the process repeatability, four cuts were performed per part (fig. 2)

### 3.3 Wire Tension and Process Parameters

The wire tension in WEDM process is a key variable with big influence on the part precision and the process stability. In thin WEDM, the importance is even higher, wire breakage can appear with reduced tension fluctuations but, on the other side, bigger tension values should provide higher precision.

The Sodick AP200L does not use a tension control system for Ø0.030 mm wire but a system of counterweights whose mass adjusts the tension acting on the wire. Apart from these masses, the wire tension depends on the friction in the different pulleys and contact parts. The counterweights applied for the cutting processes were 0, 12, 20 and 30 grams.

Finally, the cutting conditions applied in the first tests were fixed according to the experience of the operators.

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Fig. 3. Scanning performed by confocal microscopy at the central section

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### 4. Error Characterisation Procedure

In the observed procedure for normal WEDM [4], a test part of bigger dimensions was cut and then the central slide (in which the biggest errors appear) was measured.

The use of confocal microscopy can be applied to the central section and then, the acquired data can be studied in order to perform the representation of the central section of the test part (figs. 3 and 4).

The resolution in XY is 0.5 µm and the vertical resolution is 0.1 µm (the resolution is higher than that of an optical microscope but it is still comparable to the error that must be measured, a higher resolution would be better). The black dots that can be appreciated in fig. 3 are points in which the data acquisition failed. Software interpolation can be applied to reconstruct the image.

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In all these tests part cleaning turned out to be one key problem for error characterisation. All parts were cleaned using ultrasonics (using first alcohol and later acetone), this procedure eliminated the dielectric oil of the WEDM process but some re-melted material was deposited on the part surface. Mechanical cleaning using wood sticks and special watch cleaning clothes was applied but the bottom of the cut was not cleaned properly. This dirtiness causes some noise that is added to the machined profile.

### 5. Error Analysis Tool

A Matlab routine has been programmed in order to read the data of the sections obtained by confocal microscopy and compare the theoretical shape to the programmed path applying least squares adjustments.

In order to reduce the effect of the re-melted material, the program allows the user to perform the manual elimination of wrong points and applies some filtering techniques that eliminate points presenting excessive peak values with respect to the continuous mean values.

The machined path is divided into three different tracks: inlet, corner radius and outlet. The best fitting solution for each of them is calculated and the continuity relations are stated. Finally, the normal error is calculated for each point.

This routine is an important tool because it is capable to reduce the effect of the measured dirtiness by filtering and represents the error in an intuitive manner (figs. 5 and 6).

### 6. Analysis of the Results

Several parts have been cut applying different wire tension values (0, 12, 20 and 30 grams). These parts have been useful to identify the previously mentioned problems of part characterisation, optimise the matlab routine for data analysis and establish the bases for a more in-depth study that should be supported by more data in order to achieve clear conclusions.

As it could be expected from the experience in normal WEDM [1,2,3] and the reduced dimensions of the test parts, when no counterweight is disposed (0 grams, fig. 5), the wire vibration becomes important after changing the cutting direction and it does not achieve the stable position as it gets out of the part. Applying more mass, the wire tension is increased and the error decreases (fig. 6).
In all cases, the corner radius that is fitted by least squares presents deviations of +5~+10 µm. But the fitting presents an important standard deviation, not presenting important differences if a different radius is considered for the calculation of the machining errors.

7. Future Actions

The presented test procedure has been successfully applied for the analysis of miniaturised thin WEDM-ed samples. Nevertheless, it should be validated to establish a solid base for future tests.

7.1 Part Characterisation

The errors presented in this job have been measured using confocal microscopy and applying data filtration. Both techniques should be validated. The values measured by a confocal microscope have an important dependence of the reflectivity of the measured material, the dirtiness deposited on its surface and the applied light intensity. Concerning the data filtration algorithm, it should also be verified.

The validation of the measured data could be performed by comparison between the data obtained by confocal microscopy and the data obtained by other traceable measuring techniques like a CCM. For that purpose, a different geometry, in which a conventional CCM probe could be applied, will be defined.

The same test could be applied to verify the filtering algorithms. A CCM machine applies a contact force that can reduce the effect of dust particles on the part surface. Another option that will be considered is the comparison between confocal microscopy of the top and lower part surfaces and the results obtained by high magnification (x1000) optical microscopy.

7.2 Section Presenting Maximum Errors

The machining of parts by thin WEDM, due to the vise dimensions, usually cannot be performed with the nozzles in close-flow position, being the distance from the top guide to the part bigger than the distance from the bottom guide to the part. In this case, the lack of symmetry establishes that maybe the central section does not present the bigger errors. To analyse this fact, the top and the bottom surfaces of each part will be analysed and compared to the central section.

Acknowledgements

The authors want to thank the Spanish National Research, Development and Innovation Plan for supporting the research project in which the presented developments have been performed.

References