# Precision WEDM of Fir-Tree Root Slots in Udimet 720

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## Abstract

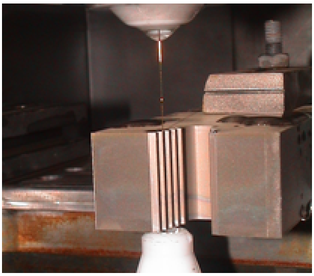
The paper outlines experimental data relating to the evaluation of workpiece integrity and dimensional accuracy following WEDM of fir-tree shaped blade root slots in Udimet 720 nickel based superalloy. The work employed minimum damage 'Clean-Cut' generator technology with appropriate multi-pass and geometric compensation machining strategies. Results indicated that surface roughness and recast layer thickness levels of 0.5µm Ra and <2µm respectively were achieved after two finishing passes, while a three-fold improvement in slot dimentional accuracy was observed when employing updated operating parameters / condition settings.

## 1 Introduction

The use of electrical discharge die sink technology for traditional mould and die/toolmaking has been steadily declining since the introduction of high speed milling in the early 1990s. In contrast, wire electrical discharge machining (WEDM) has significantly expanded its application base over the same period due to developments in process capability and material removal rates (up to a 5-fold increase). In addition to its use in more traditional industry sectors, it is finding increased application in several niche/high value areas for the production of bio-medical implants, micro electronic devices and motorsport equipment [1]. Despite the previous reluctance by the aerospace industry to employ WEDM to any great extent due largely to historical considerations concerning the thermal nature of the process and potential adverse workpiece integrity effects, its use is currently under scrutiny for the machining of blade root slots in aeroengine turbine and compressor discs. Such slots are currently broached by most aeroengine manufacturers to a nominal tolerance of ±5µm. Interest in WEDM has been brought about by recent progress in generator design/operation which has allowed precise control of electrical pulses at ultra high frequencies (in the range of 2-3MHz for final finishing regimes) thereby minimising/eliminating workpiece surface damage [2].

## 2 Experimental work

Workpiece material was 37mm height powder metallurgy (PM) Udimet 720 nickel based superalloy with a bulk hardness ~48HRC. Wire machining of fir-tree root slots was carried out on an Agie-Charmilles Robofil 240cc five axis machine employing ‘Clean Cut’ generator technology using uncoated 250µm diameter brass wire, see Figure 1. Machining sequence involved one roughing and two finishing passes. Workpiece surface roughness was measured using a Taylor Hobson Form Talysurf 120L with a 0.8mm cut-off length and 4mm evaluation length.



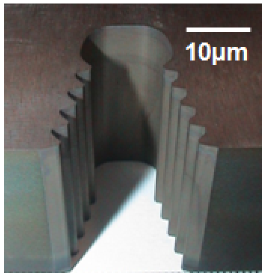



Figure 1: WEDM of fir-tree slots

Recast layer evaluation and microstructural analysis were conducted on a Leica DM LM microscope and a JEOL 6060 Scanning Electron Microscope (SEM). Wire machined fir-tree slot accuracy was assessed using a SmartScope optical measurement device (~ ±2µm precision). Slots were scanned and the profiles were then compared against the original ISO file used for machining.

## 3 Results and discussions

The average surface roughness (Ra) measured for the machined slot was ~3.5µm after roughing (R) compared to ~0.5µm following the second trim pass ( T2). Figure 2 details 3D topographic maps for the 2 samples which show characteristic EDM surfaces with irregular distribution of peaks and valleys especially after roughing.

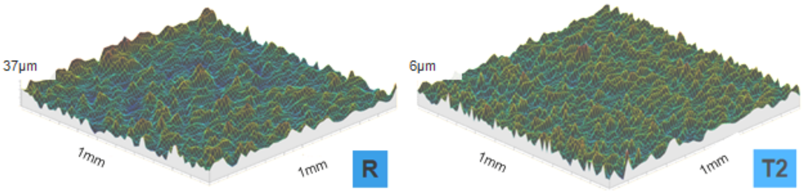



Figure 2: Surface roughness 3D mapping of roughing and T2 surfaces

Figure 3 shows the fir-tree profile with corresponding recast layer and microstructure for a sectioned machined slot after roughing and T2 respectively. The average recast layer thickness observed after roughing was ~8-10μm along the machined surface which dropped significantly with subsequent finishing passes to <2μm after T2.

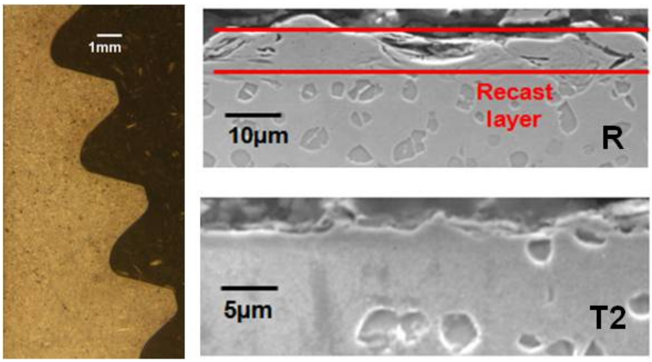



Figure 3: Fir-tree profile, recast layer and microstructure after roughing and T2.

In terms of geometrical accuracy, initial evaluation suggested large machining inaccuracies especially at the corners where the error ranged between -10 and +21μm, see Figure 4a. This was due to lack of appropriate machining strategies which were unavailabe at the time. Subsequent tests adjusted operating parameters in the first finishing regime to allow better control of geometrical details, resetting the wire offsets during finishing and tuning of machining strategies principally by affecting the reference voltage between the wire and workpiece to control servo speed. Figure 4b shows the revised fir-tree slot profile which indicates significantly enhanced component accuracy with a minimum error of 5μm and a maximum error of 7µm, where the latter was thought likely to be the result of dust on the machined surface. Similar accuracy profiles were obtained for both the top and the bottom of the slot, however it was not possible to assess the straightness of the slot using the OGP Smartscope, for which a different / 3D measurement device is required. Further anticipated improvement in accuracy / precision as a consequence of utilising finer wires (typically 100µm) and further finishing passes was discounted as this would have compromised process productivity.

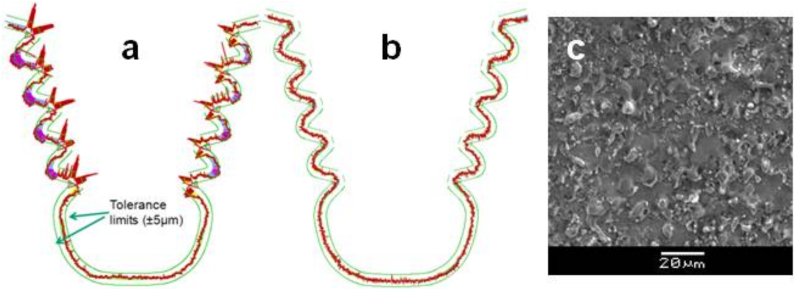



Figure 4: (a) Intial fir-tree slot (b) revised fir-tree slot accuracy profile and (c) WEDM-ed slot surface

## Conclusions

Appropriate finishing / trim cut regimes produced an 80% reduction in average recast thickness and workpiece roughness when compared to roughing. Despite a quoted machining accuracy of ±5µm, initial finishing trials produced error deviation values of up to 21µm. With appropriate tuning of machining strategies and ancillary operation changes the error was reduced to a maximum of 7µm.

## References:

[1] Yan, M.-T. and Y.-P. Lai, Surface quality improvement of wire-EDM using a fine-finish power supply. Int. J. Mach. Tools Manuf., 2007. 47(11), 1686-1694.

[2] Antar, M.T., Soo, S.L., Aspinwall, D.K., Cuttell, M., Perez, R., and Winn, A.J., WEDM of Aerospace Alloys Using 'Clean Cut' Generator Technology: in the Proceedings of the 16th International Symposium on Electromachining (ISEM XVI), Shanghai, April 2010, pp. 285-290. ISBN: 978-7-313-05630-6.