Re-evaluating the EDM Process For Titanium Machining

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GF AgieCharmilles

Total Sales 2012
CHF 3.8 billion

GF Automotive

GF Piping Systems

GF AgieCharmilles
Electric Discharge Machining: What is it?

- No mechanical contact between the tool and the workpiece
- A controlled discharge is produced in the gap filled by a dielectric liquid
- The discharge melts and evaporates the workpiece material:
  - In die-sinking EDM the electrode shape is “printed” in the workpiece
  - In wire-EDM a profile is cut along a predetermined path
Electric Discharge Machining: The Reality of the Process

😊 What’s great about the process:
• EDM can remove material that is otherwise difficult to machine.
• EDM does not face the same machining challenges of today’s difficult to machine alloys.
• Component material only needs to be electrically conductive.

😊 What are the challenges:
• Material is removed by heat, thus causing the potential for a recast layer on the parent material.
• The electron flow associated with the EDM process can cause the electrode material to migrate to the surface of the manufactured part.
Advances in Wire-EDM

Micro wire EDM machines:
• Taper angles 3° / 80mm
• Wire diameter range
  ➢ 0.07 – 0.33 mm
  ➢ 0.02 – 0.05 mm (option)
• Automatic wire changer: **Twin-wire** = 2 x 8kg of wire spools

- Grain of salt 60 µm
- Wire diameter used in W-EDM down to 20 µm
- Hair section

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Integration of 5\textsuperscript{th}/6\textsuperscript{th} axes

Spiral workpiece, (enlarged) produced with integrated turn- and tilting axis rotary table on a wire-EDM machine

Spinal column part manufactured out of titanium with a rotary table

Courtesy of Jauchschmider
Dedicated EDM machines:
- Using integrated axis
- Taper angles >30 degrees
- Wire diameter range
  - 0.07 – 0.33 mm
Integrated Vision Units

- In process measurement
  - Repeatability less than 1µm
  - Accuracy ±1.5 µm
- Application: Machining of teeth of endoscopic pliers
- Material: Stainless steel
- External diameter: 0.5mm
- Wire diameter: 50 microns
**Generator Improvements**

Limits of Wire-EDM for the removal rate and affected zone

- The heating of the wire and part surface  \( \Rightarrow \) RMS current
- The power dissipation on the generator  \( \Rightarrow \) Switching frequency, pulse magnitude

**Solution: Shape of intensity pulses**

- The pulses have to be easy to generate and are constrained to maximize the mean current (IAV) and minimize the IRMS
- The independent degrees of freedom are:
  - intensity
  - current slope
  - pulse duration

\[ \Rightarrow \text{Triangular shapes} \]
History of Generator/Servo technology

Key technology improvements:
- MOSFET and FPGA (programmable logic) allow the integration of large discrete logic boards in a single module.

1995-2004
- Metal removal 300mm²/min
- Efficiency increases from 7% to 33%

2004 -
- Metal Removal 420mm²/min
- Efficiency increases to 80%

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Power Electronics

Qi : Fast Power MOSFET  500 [V]
Di : Ultra Fast Recovery Diodes
Generator performances

- Generation of $I_{\text{MAX}} = 1000 \, [\text{A}]$ triangular and trapezoidal current pulses
  - $\Rightarrow$ HIGH Current power MOSFETS & Ultra Fast Recovery Diodes
- Slope up to $600 \, [\text{A/}\mu\text{s}]$
  - $\Rightarrow$ Very Low Line & machining zone Inductance $< 0.5 \, [\mu\text{H}]$
  - $\Rightarrow$ High Power Supply Voltage up to $320 \, [\text{V}]$
- Short pulse duration $50$- $1000 \, [\text{ns}]$ and high repetition frequency
  - $330 \, [\text{kHz}]$
  - $\Rightarrow$ Very high speed Power Mosfets & Diodes.
- Very hard EMC Environment
  - $\Rightarrow$ Well immunized control system.
Performance Results

Heat affected zone HAZ for roughing: (discharge time 1.4 $\mu$s) with different current rise slopes

Current Slope 300 A/$\mu$s (Standard Generator)

Current Slope 500 A/$\mu$s (Clean Cut Generator)

$\rightarrow$ Advantage of increasing pulse current slope: keep the in-depth HAZ constant and increase the machining speed
Performance Results

**Legacy Generator Results:**
Optimised for steel and Carbide materials. Settings developed for other materials.

- Large area of thermal damage
- Rough, inconsistent finish
- Large amount of recast

**New Generator Results:**
Complete digital data acquisition and optimisation. Pulse tailored to individual materials.

- Minimum Recast
- Fine, consistent finish
- Efficient stock removal rate
Quality in surface finishes

- Programmable surface finish for meeting aerospace and medical applications and manufacturing demands
- May eliminate the need for subsequent polishing
- Real-time monitoring and recording of quality process indicators:
  - Historical analysis
  - Data Acquisition
Quality in surface integrity

**Programming the right spark energy = respect of surface integrity**

Use of MHz range pulsed discharges eliminates recast layers and prevents unexpected fatigue failure of machined parts.

*After roughing, recast layer < 6 µm*

*After 4 finishing cuts, recast layer is not visible*

Courtesy of Birmingham University
Results – Recast Layer

Detailed view of the recast layer after 4 finishing cuts

Courtesy of Birmingham University
Only a slight softening is measured near the part surface (R- roughing, T4- last finishing cut)
Results – Surface Roughness/Topography

Topographic 3D profiles show average surface roughness values (< 0.38µm) as shown below.

Sa = 0.38µm

Courtesy of Birmingham University
Fatigue Performance of Ti6246

Fractography analysis

- Fatigue testing was conducted at room temperature using a 4-point bend configuration.
- No statistically significant differences were evident between the fatigue performance of milled and finishing WEDMed specimens.

Ti6246 S-N curve

Maximum applied stress (MPa)

N (cycles to failure)
Current Challenges for Applications

- Standard wire-EDM process uses brass wire: Slight Copper and Zinc contamination occurs at the surface of Titanium alloy parts
- Chemical post-processing may be needed

EDX - Analysis

Klocke et al. (WZL Aachen University)

SEM Analysis

Steinemann, Metal Implants and Surface Reactions, Injury Vol 7, 1996

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Surface modification for Zn-free applications

- Rough cut: Brass wires
- Finishing cut: Titanium, Tungsten, Copper, Steel wires

- Special strategies in carbon-based dielectrics used for surface modification during finishing operation.

- **Biocompatible** Titanium and Tungsten carbides, steel are deposited in 1-5 \( \mu \text{m} \) thickness layers at the surface of parts.
Zinc-free surfaces on steel

- Surface modification with Tungsten wire on steel using oil dielectric
- Twin wire strategy: roughing brass wire, finishing-coating Tungsten wire
- Tungsten-carbon surface alloy of 1-3 μm thickness
- 40 mm part height, Ra 0.2 μm

<table>
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<th>Surface</th>
<th>C-K</th>
<th>Cr-K</th>
<th>Fe-K</th>
<th>W-L</th>
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Electric field: Oxygen deposition

During ignition delay time: electrolysis

EDM pulse generator

Water dielectric

TiO₂ coating by WEDM
During spark: boundary plasma thermal oxydation
Technological Parameters for TiO$_2$ Coatings

$T_{on}$ 0.9 $\mu$s, -120 V, 6 A, Gap 70 $\mu$m
Gap 60 $\mu$m
Gap 50 $\mu$m
Gap 40 $\mu$m

$T_{on}$ 6 $\mu$s, -120 V, 3 A
Decreasing gap: 10 -> 0 $\mu$m
Sparking: thermal oxidation

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TiO$_2$ Coatings

Substrate: Ti-6Al-4V
Summary

✓ Titanium manufacturing needs to change with the times.
  ➢ We **must** lower cost and improve performance.

✓ We **must** break the mindset that the EDM process is still the same.
  ➢ Results are clear about intelligent generator performance.

✓ We **must** work together to bring about change we can believe in!
  ➢ Joint projects to benchmark old processes and test new ones.
Thank you very much for your attention...

Achieve more...

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