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Procedia CIRP 6 (2013) 292 – 296
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The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)

Micro-EDM-milling

Development of new machining technology for micro-machining

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Abstract

This paper investigates the physical basis and the industrial feasibility of micro-EDM-milling; the characteristics of this innovative technology are the following: (i) electrodes are of standard size – it is no more necessary to prepare electrode as in die sinking , (ii) electrodes are of small diameter (<0.8mm) and long (~40mm) – this make them flexible, (iii) electrodes are straitened by a dynamic self-centering effect when rotating at high speed , (iv) work piece material is removed by the sparking only at the tip of the electrode and (v) electrode wear is compensated by programmed declining trajectory.
All this makes Micro-EDM-milling a quite unconventional and original technology. The most innovative point is the use of long, thin and low cost electrodes. Its interest is due to the absence of cutting forces, this technology allows machining deep cavities of high precision without any risk of tool break.
Micro-EDM-milling has a strong innovative potential: today there is no machining technology that is able to perform so accurate, fine detailed cavities with such high aspect ratio (h/l > 30). This new technology could be placed as an independent machining technology, but also as a complement to die-EDM-sinking as well as to high speed milling.

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Keywords: micromachining, EDM, milling, EDM-milling, standard electrode, rotating electrode, self-centering effect, wear compensation.

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doi:10.1016/j.procir.2013.03.023

1. Introduction:

1.1. . EDM-milling & micro-EDM-Milling

EDM-milling, the "historical" starting point of micro-EDM-milling, is somehow in-between die EDM sinking and wire EDM cutting. EDM milling tools are tubular copper electrode rotating at high speed in the dielectric oil and removing the work piece material by sparking. By analogy to conventional milling, it is the movement of the electrodes that generates the work piece geometry by subtraction of material. EDM milling is similar to die EDM sinking as it performs non traversing cavities (fig.1, fig.2), but it is also similar to Wire EDM cutting as tubular electrodes are standard consumable parts and the wear is compensated by the electrode's renewal (fig.3). In the nineties, this technology has been developed at Charmilles for tubular electrodes from diameter 0.8 mm to 12 mm (prototype presented at EMO 1998).

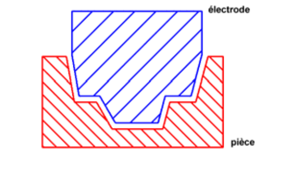

Fig. 1. Conventional Die Sinking

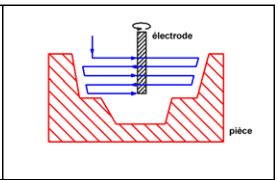

Fig. 2. EDM milling

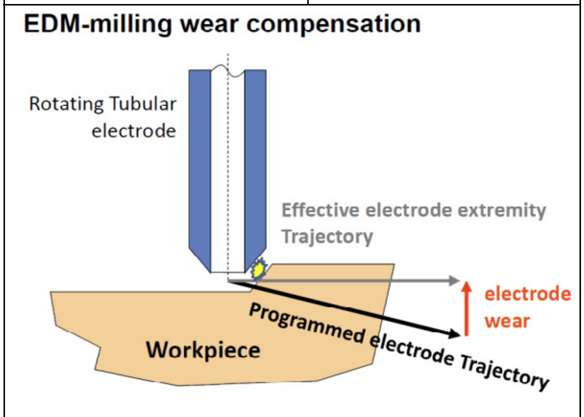

Fig. 3. Electrode wear compensation in EDM milling

Micro-EDM-milling uses basically the same ideas but for much smaller electrodes (diameter smaller than 0.8 mm). At this size the electrodes are flexible and it is not obvious to use them as accurate milling tools. Therefore, this situation had never been studied. To solve this difficulty, micro-EDM-milling use a dynamic effect of rotating at high speed the electrode to rigidify and strait it. The sparks occur at the tip of this tool, so to remove the material without cutting forces. This fact is of great interest as it allows to machine deep cavities with high accuracy without any risk of tool break. The wear of the electrode is compensated by a programmed declining trajectory.

All this makes the machining conditions quite unconventional (typical hydrodynamic, sparking plasma in dielectric with velocity gradient, mechanical stability of flexible rotating electrode). So the physical basis of this process has to be investigated in order to prove the industrial feasibility of this innovative technology. The main results of this research are here presented.

2. Experimental configuration

The research on this new EDM technology was based on an EDM-milling machine. A high speed spindle has been added. As shown on fig.4 the electrode is fixed with a bras cylindrical part that is isolated from standard HSM tool holder. The current necessary to sparks is brought to that bras cylindrical part through graphite contacts.

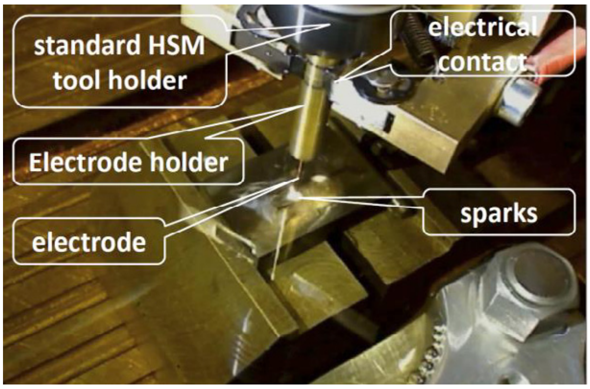

Fig. 4. Micro EDM Milling machining – experimental electrode holder

To be able to measure the stability of the electrode's tip, a dedicated stroboscope with convenient optic system has been developed.

3. Physical basis

3.1. Electrode Dynamic stabilization

Typical micro-EDM-milling electrodes are 40mm long for a diameter from 0.8 to 0.2 mm, they are very flexible. One fixes them at the center of a brass cylinder (that allows the electrical contact). The electrode is brazed in a fine accurate drill hole centered with the spindle axis.

For stabilization purpose a preforming operation has to be done – a bit like forming by turning plastic material. Once prepared as described, the electrode can be used for machining, it remains aligned to spindle rotation axis and resists to perturbation. Thus, high speed rotation has a self-centering effect; this effect is due to Steiner rule, minimizing inertial momentum; obviously the system has to be kept outside vibration modes.

The convenient spindle speed – also suitable for EDM machining - depends mainly of the electrode diameter, it is about 10’000 rpm for ø 0.2 mm copper electrodes (fig.5).

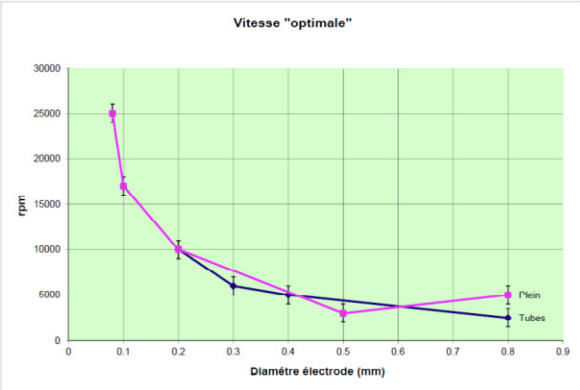

Fig. 5. Optimal rotation speed for micro-EDM-milling according to electrode diameter. The electrode peripheral linear speed is about contant.

3.2. Hydrodynamic aspects

Hydrodynamics efforts on the electrode are estimated using CFD (Computed Fluid Dynamic) for two different situation of micro-EDM-milling:

a) central pocketing - the electrode is machining a flat area
b) border contouring – the electrode moves along a wall

Fig.6 shows result of simulation of the case “border contouring”: the effect on the tool is a small attractive force in Z + and a small repulsive force in Y (the wall). This repulsive force is of ~1mN for an electrode ø 0.2mm and ~2mN for an electrode ø 0.8mm. This force is small for electrode of 0.8 mm diameter but it cannot be neglected for the smallest electrodes: With 1mN, the deflection of an electrode ø 0.2mm 40mm long would be greater than 1mm. In the practice this is counterbalanced by the dynamic straitening and self-centering stabilization, as it is demonstrated by the machining of the cavity shown on fig.10 (in that case the precision on the vertical walls is better than 0.03mm).

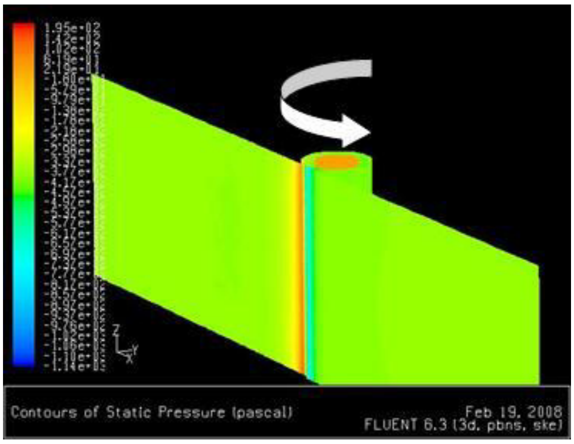

Fig. 6. Contour of static pressure along a wall. The wall is seen from the material side and the electrode is behind. We clearly see the pressure gradient which involves a force in the horizontal plane.

3.3. EDM plasma of high speed rotating electrodes

This topic has been studied at EPFL/CRPP. For a typical milling speed of 10'000 rpm, the electrode turns only half a degree during a spark duration, which last 8 microseconds. Hence, the electrode is effectively stationary during the discharges, and the plasma was not noticeably influenced by milling compared with die-sinking operation. The spectrum of the initial breakdown was dominated by continuum emission and a broadened H-alpha line, coming from the water dielectric, the rest of the discharge was mostly metal line emission from copper, iron and chrome from the electrodes. There was no significant spectral dependence on milling speed nor gap distance.

Telescopic videos of the discharge gap clearly showed that the spark is much smaller than the electrode dimensions.

In other words, we can say that the plasma typology of this particular EDM machining is similar to standard EDM. Even if the rotation speed is quite high, the relative velocities are small compared to spark dynamic.

4. Demonstration & achievement

4.1. Feasibility of micro-EDM-milling.

To improve the wear predictability and efficiency with lower wear, we implement on the experimental configuration an optional short pulse generator (~500ns) from AgieCharmilles. This one is built for drilling, with electrodes of diameters between 0.2 to 1.0 mm, small holes. The impulses are shorter than the classical ones and the opposite current part is suppressed. With this generator, we have obtained a 10% increase in removal rate and a 15% decrease in wear. A special generator with shorter pulls (~50ns) would be needed to reduce even more the wear.

Using copper electrodes several trials have been done with various electrical settings (spark energy). One shows that the performances are the same in milling or drilling machining. It was also possible to measure directly the wear, which is an important parameter to pre-compute the tool path for a complex shape pocket.

Using this, cavities 2 x 4 mm have been machined fore for checking the topographies.

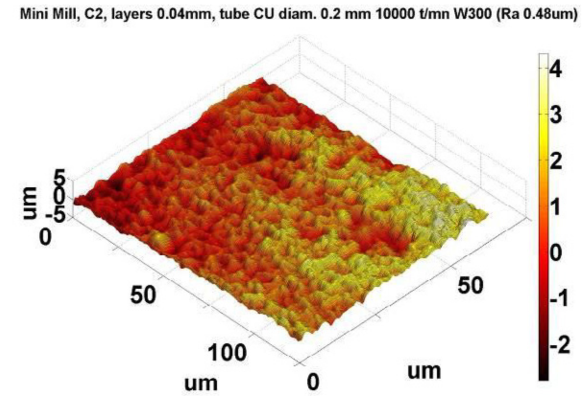

Fig. 7. Micro EDM Milling machining with Cu **tube** 0.2 mm Micro Hole 2.2nF -200V 10000 rpm

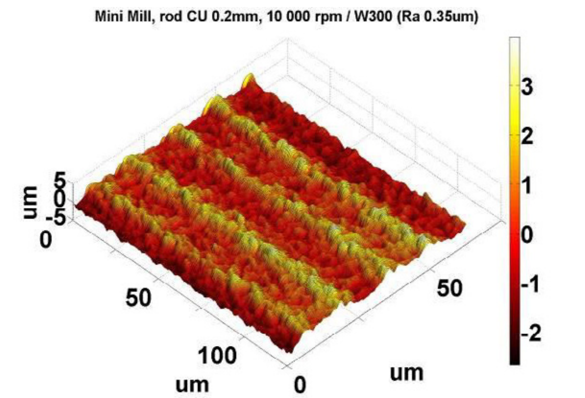

Fig. 8. Micro EDM Milling machining with Cu **rod** 0.2 mm Micro Hole 2.2nF -200V 10000rpm

As it can be seen on fig.7 the resulting surface is almost flat. This is due to the fact that with tubes the wear gives a truncated conic shape to the tool (shown on fig.3). Then when the passes overlap is smaller than hole diameter the resulting machining surface is flat. This is not the case with plain rods (fig.8) – the wear gives conic shape to the tool and excess of material is visible – fortunately in that case, the scallop error can be reduced as desired by reducing the step between paths.

4.2. Machined parts with high aspect ratio in hard steel.

The ability of machining high aspect ratio cavities is the strong point of this technology. To demonstrate this fact we defined a cavity with a groove, a rib and a pouch. As can be seen on fig.9 two such cavities with homothetic dimensions have been machined. The first Cavity 6 x 3 x 2 mm with a ø 0.8 mm Cu electrode and the second 2.25 x 1.25 x 0.75 mm with a ø 0.3 mm tube Cu electrode.

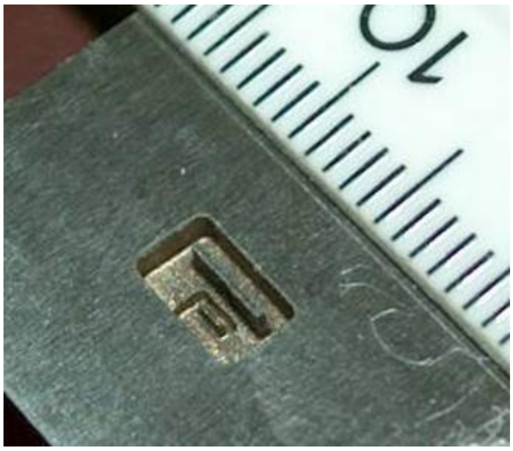

Fig. 9. Micro EDM Milling machining with electrode diameter 0.8 and 0.3 mm

A cavity 4mm deep with grove and rib of 0.15mm thickness in hard steel has been achieved. This proves that an aspect ratio h/l > 30 is reachable.

4.3. Rods and tubes in copper or brass convenient electrodes for micro-EDM-milling.

Several materials and geometry have been checked for the electrode. It appears that rods and tubes in copper or brass are convenient for micro-EDM-milling. For very small diameter (in fact wire at this size), rods will be preferred as it is very difficult to provide a thin tube with concentric hole; in that case, the mass inhomogeneous repartition affects the dynamic rotation centering.

Tungsten carbide rods tubes and rods have been checked without success. In that case, the electrode is easily breakable while rotation at high speed.

5. Conclusion

The micro-EDM-milling has a strong innovation potential: today there is no machining technology that is able to perform accurate, fine detailed cavities with such high aspect ratio. As shown on fig.10 deep groves as well as free form details are feasible. This new technology could be positioned as an independent machining technology but also as a complement to die-EDM-sinking as well as to high speed milling.

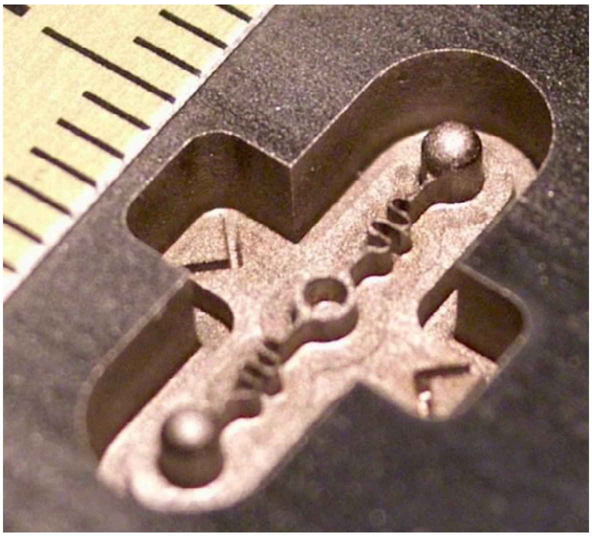

Fig. 10. Micro EDM Milling machining – micro cavity of complex shape with high aspect ratio.

Acknowledgements

The authors wish to thank particularly the academic an industrial partners for their work and contribution to this research: Patrick Haas (hepia), José Alberty (hepia), Hervé Sthioul (hepia), Christoph Hollenstein (EPFL), Allan Howling (EPFL), Roger Delpretti (HEIG-VD) Georg Wälder (Agie Charmilles), Roberto Perez (Agie Charmilles)

The authors also wish to thank the KTI/CTI (Swiss funding for research) for its support.

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