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Development of a new generator for Die Sinking electrical discharge machining

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Abstract

Commonly, on Die Sinking Electrical Discharge Machining (DS EDM), a special generator enables current pulses in sinusoidal or triangular shapes, only in a single polarity. The duration and the amplitude are adapted to the machining sequence, allowing the achievement of different surface finishing. By using a new configuration, it is shown that if one applies pulses of current in both polarities, related together but with a certain ratio between the positive and the negative peaks current, machining results could be improved. The purpose of this new generator is the ability to control with great flexibility the generation of these pulses, in terms of durations, amplitudes and sequence. These parameters can be independently selected for the positive and negative polarity and modified during the machining. One can also choose a special predefined or settable sequence of pulses. The generator includes also the double polarity ignition and the high-speed gap breakdown detection. An embedded programmable circuit (FPGA) provides a high-speed control of the sequence. Machining tests have been performed in order to explore and quantify different sequences of pulses in terms of machining results and performances achieved, compared against the current situation.

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Keywords: Die Sinking EDM; surface finishing generator; surface treatment; improved surface finishing, improved remouval rate

1. Introduction

The genesis of this development comes from an observation made during some machining tests with a defective element on the hardware generator.

Previous researches [1] have been conducted that demonstrate the improvement of super-finished surfaces by using a stochastic orbiting, a standard resistance-capacitor generator and a low stray capacitance power circuit.

Anyway, in most DS surfacing machining [2], the use of sinusoidal current pulses is also commonly applied. The first half-sine of the current, achieved by a LC (inductor-capacitor) discharge circuit, is used for the erosion. The current pulse duration and its peak depend on the LC combination and the charging voltage of the capacitor at the time of the discharge.

The addition of a diode cut off the unwanted polarity and let pass only the first half-wave without oscillations (Fig 1a).

Thus, during tests which implemented this type of machining configuration but with a generator having a dysfunction (the diode was not playing its role), the second half-wave was not cut (Fig 1b), leading to an unexpected positive effects on the removal rate performance: the machining speed has increased, the surface roughness has slightly reduced and no significant effect on the electrode wear has been observed.

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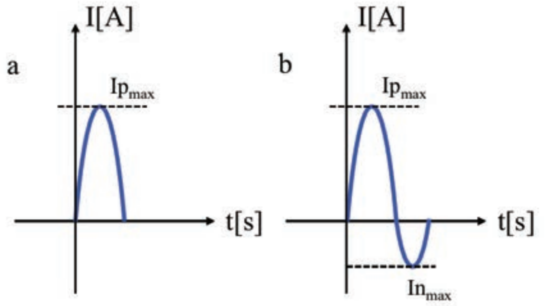

Fig. 1: a) Expected pulse, b) Altered pulse

In order to assess the improvements that could be achieved by the generation of current pulses, easily configured by tuning the Ip_{max} and In_{max} amplitudes (Fig 1b), durations and some specifics pulses sequences [3], a specific study was undertaken [4].

Nomenclature

gap	Distance between the electrode and the workpiece
FPGA	Field Programmable Gate Array
DS	Die Sinking machine
CBOX 322	+GF+ DS Standard machining
Ip_{max}, In_{max}	Positive peak current, Negative peak current

2. Topology of the new generator

The current architecture of standard generators, using the principle of a LC discharge circuit, has the following disadvantages and cannot fit with the demand:

- The amplitude of the current depends on the voltage of the capacitor at the time of the gap breakdown, which is not guaranteed in the actual concept, and lead to generate pulses where the peak current is not each time the same
- Inability to independently adjust the maximum amplitudes Ip_{max} and In_{max} and their durations
- Difficulty to generate predefined sequences having alternating polarity between each sequence

The topology proposed to meet the specifications is a classic H-bridge [5] [6] to generate the spark current (Fig 2), coupled with an ignition phase made by a resistive current limitation.

The current (I) and the voltage (U) can cross the bridge in all polarity configurations, allowing a recovery four quadrants (I> 0 and U> 0, I> 0 and U <0, I <0 and U <0, I <0 and U> 0). Transistors M1, M2, M3, M4 and their associated diodes are switched for injecting or releasing current into the discharge circuit (similar to an inductive load).

The prototype carries out triangular current in both polarities and the amplitude of each polarity and duration are controllable. One can thus generate large scale of bipolar pulse packets that are fully configurable.

The replacement of sinusoidal pulses by triangular is not significant in terms of machining results.

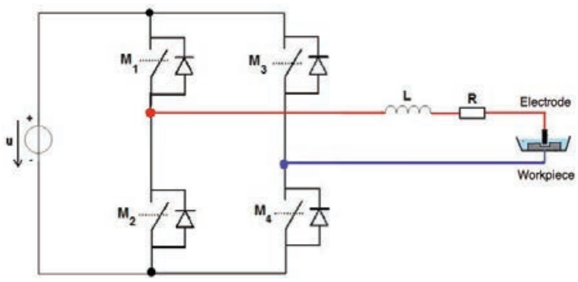

Fig. 2: H-bridge topology

The power stage must be completed by an ignition source and a high-speed detection of the gap breakdown.

Before releasing the main current in the gap by the H-bridge, it is necessary to apply a voltage, called the ignition voltage, which will first create the breakdown.

A fast electronic controller is integrated on the board to measure the gap voltage. It will detect the sudden drop (between the ignition voltage value and the gap voltage value) and initiate the generation sequence of the current pulse. This bipolar ignition phase limits the current to low amplitude and short duration (as compared to the currents of the triangular pulse Ip_{max} and In_{max}) and it is carried out by a simple resistive limitation.

The system is controlled by a programmable circuit (FPGA) and includes a communication allowing the configuration of the assembly.

This concept allows complete control of all parameters and provides reliable and repetitive generation of the current pulses.

2.1. Operating modes

Figures 3 to 9 show the various possibilities of generation of current pulses, according to the programmed operating mode. For each sequence, the amplitudes of the positive Ip_{max} and the negative In_{max} current are separately configurable.

- Mode #1 (Fig 3): only positive unipolar sequence

Fig. 3: Mode #1, only positive current

- Mode #2 (Fig 4): only negative unipolar sequence

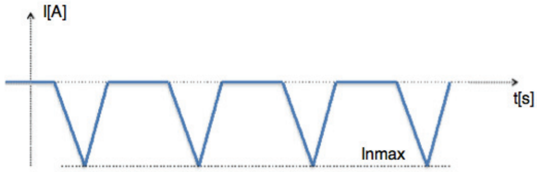

Fig. 4: Mode #2, only negative current

- Mode #3 (Fig 5): Positive bipolar sequence. The first pulse is of positive polarity.

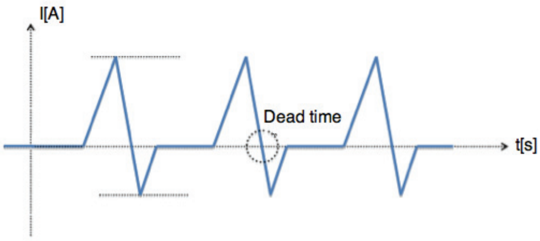

Fig. 5: Mode #3, bipolar current (positive first)

- Mode #4 (Fig 6): Negative bipolar sequence. The first pulse is of negative polarity

Fig. 6: Mode #4, bipolar current (negative first)

In modes #3 and #4, the dead time between the positive and the negative parts can be finely adjusted.

- Mode #5 (Fig 7): Packet sequence.

Fig. 7: Mode #5, current packet sequence

This last sequence allows generating the mode #4 just after the end of the #3. One can specify the number of pulses contained in each packet, for example 4,8,12 or 16. The alternation of these 2 modes is automatically generated. The “dead time” (Fig 5) is nil but could be eventually modified.

In order to fully control the end of the current generation, it should be noted that at the end of every single pulse, the gap is short-circuited by a programmable time, allowing the return to zero current without overshoot.

The transistor driving is automatically adjusted and it is deducted from the period of the main pulse (Fig 8 point a), whatever the used operation mode, making possible to completely eliminate the overshoot (Fig 8 point b) with respect to a case without management of the short circuit (Fig 8 point c).

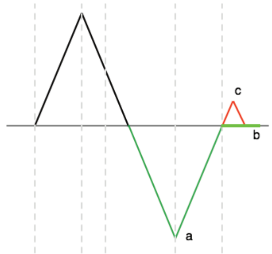

Fig. 8: With short-circuit (point b) and without (point c)

Another feature is the capability to generate trapezoidal shaped pulse (Fig 9) for a possible further increase of the removal rate.

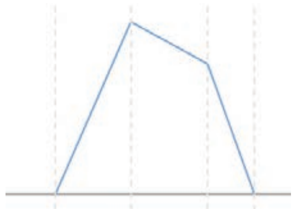

Fig. 9: trapezoidal shape

Although the used topology is classical, the innovation lies in the ability to:

- Finely weight the amount of energy between the primary and the secondary pulse directly attached to it
- Adapt in real time the pulse sequences
- Generate predefined sequence

These characteristics are new for this kind of surfacing machining.

3. Tests on bench

Before evaluating the machining performance of these new modes of operation, preliminary bench tests were conducted to validate the hardware and firmware design.

We can see in the figure 10 the complete generator. The unit is very compact and can easily fit in a place close to the machining area to minimize parasitic effects, due to the increase of the capacitance between the electrode and the workpiece and reduce the overall inductance by shortening the cable connections to the gap.

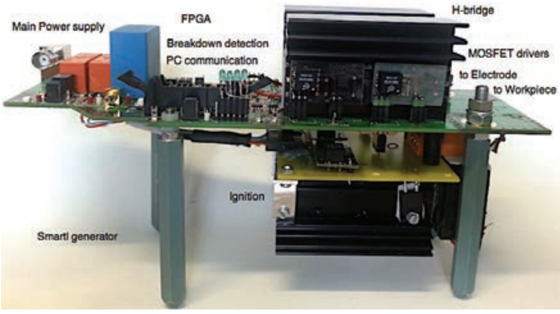

Fig. 10: The SmartI prototype generator

The figures 11, 12 and 13 depicts the oscilloscope traces of the mode #3 with different current peak balance between the two parts.

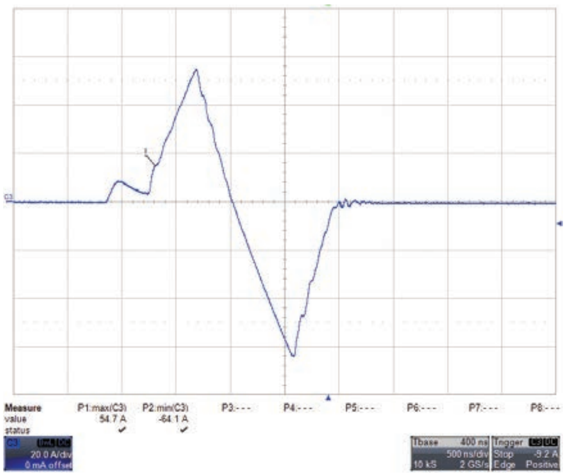

Fig. 11: Mode #3 with symmetrical parts

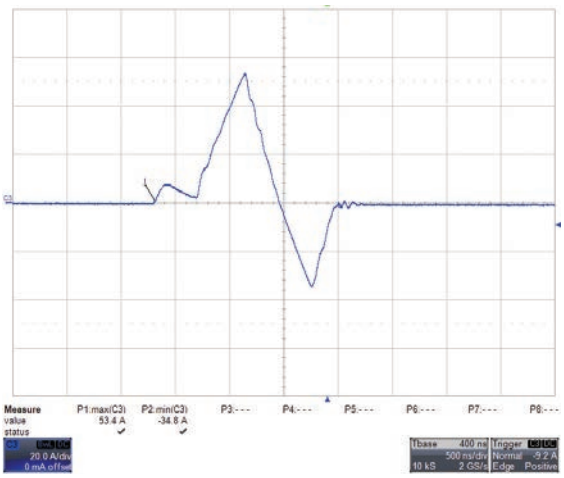

Fig. 12: Mode #3 with a positive part greater than the negative

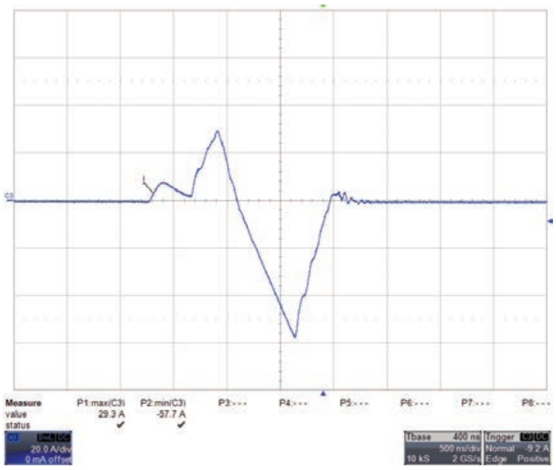

Fig. 13: Mode #3 with a negative part greater than the positive

4. Tests on machine

The machining tests aim at proving the effectiveness of new forms with very fast bipolar currents. So we looked at the performance of these new currents, in order to compare with machining standards in terms of machining removal rate, roughness and machining time.

4.1. Integration on the machine

The machine employed to achieve the integration and the machining tests is an entry-EDM machine. The small size, the simplicity and the accessibility of this machine allowed an easy adaptation of the cabling. The various modules of the spark generator are synchronized by the control of the machining process. The ignition module is already present on the machine; it was not necessary to use this functionality. However, the ignition voltage on our prototype also serves as a source for generating the pulses, so we had to adapt the behaviour of the machine ignition module to maintain voltage during the discharge.

At the time of the redaction of this paper, only one type of configuration was applied and only the machining time and the wear were used to judge the efficiency (see Table 1). Additional tests must obviously be made in order to confirm the initial results and explore all the potentialities.

4.2. Tests methods

To achieve a continuous machining with a minimum of contamination, a steel plate (W300) of 1 [mm] of thickness has been used. The part was machined on a slice with a square electrode of 15 x 15 [mm] (Fig 14). This allowed us having a good clearance of material from each side of the plate.

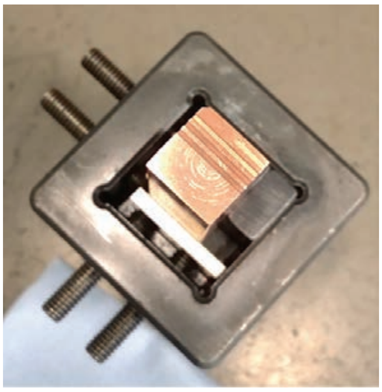

Fig. 14: Electrode view from below: the trenches matches with the machining tests

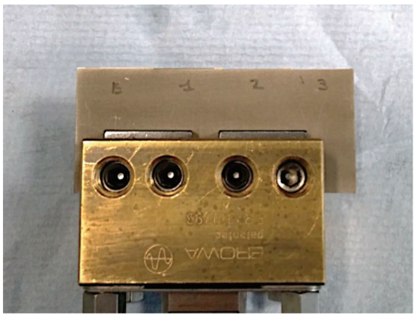

Fig. 15: The steel plate with 4 different machining areas

The machining performance is conventionally defined by:

- The machining speed (material removal rate). For comparison, we attempted to obtain the same depth in each test (verified with a micrometer table)
- The roughness and the appearance of the workpiece, measured with a Perthometer (roughness probe)
- The electrode wear, also measured with a Perthometer. We looked at the maximum depth.

4.3. Machining results

On the steel plate (Fig 15), there are three complete machining. The last slot is reserved for the fine-tuning.

- CBOX 322: the actual reference machining
- SmartI_a: machining using the prototype, generating a negative unipolar current of -40 [A] (Mode #2)
- SmartI_b: always with the prototype, generating a bipolar current, first negative of -40 [A] and then immediately after +40 [A], as symmetrical as possible (Mode #4)

For the standard CBOX 322, the reference speed and all the machining conditions are taken from the Copper/Steel technological tables of the +GF+ machine. The minimum pause time is 27 [µs]. For machining using the SmartI prototype, the same technological parameters have been used. The Ignition voltage was set up to 180 [V].

The tables 1 and 2 show the machining results of the CBOX 322 compared to the trials using the new generator (SmartI_a and SmartI_b).

Table 1. Machining results of CBOX 322, SmartI a and SmartI b

Machining test	Peak current [A]	Current pulse width [ns]	Roughness [µm]
CBOX 322	-30	660	1.055
SmartI_a	-40	516	1.130
SmartI_b	**-40/+40**	**967**	**1.286**

Table 2. Machining results of CBOX 322, SmartI a and SmartI b

Machining test	Wear [µm]	Depth [mm]	Machining time [min : s]	MRR* [mm³/min]
CBOX 322	108	0.293	15 : 18	0.29
SmartI_a	156	0.27	18 : 03	0.22
SmartI_b	**114**	**0.31**	**8 : 51**	**0.53**

* Calculated Material Removal Rate, based on the depth and the machining times

The SmartI_a unipolar mode is less efficient than the benchmark (see Table 2). Indeed, the delay between the breakdown and the rise of the power current creates extinctions. With the same energy (although the pulse width is more compressed and the amplitude is higher), roughness, wear, and the machining time are increased.

However, the bipolar mode reverses the trend and the time needed to reach the same depth is practically divided by 2 (-42%).

The fact that the roughness slightly increases and the wear decreases, compared to unipolar mode, can be explained by a material re-deposition on the electrode. One can also observe a brighter appearance to the electrode for this test. This hypothesis could not be confirmed by the measures, but it would be interesting to do further tests with currents in reverse polarity and asymmetric.

5. Conclusion

In this study, DS EDM using a new innovative and flexible generator topology has been conducted. The pulse duration, the peak current, the change of polarity can be individually and easily modified.

The first tests show drastically improved machining time and material removal rate compared to the actual performance of some DS surface machining. The new generator offers high flexibility for the current shape generation and a lot of new combinations.

At the time of the paper redaction, we have been able to perform only the mentioned machining tests. It will take time to explore all the capabilities. Further tests have to be done, especially using specific balance energy between the two polarities and also applying the sequence modes, in order to verify if surface quality, electrode wear and sparks localization can also be improved, while maintaining the same achieved removal rate.

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The implementation of this new generator on the targeted machine, the adaptation of the existing hardware to host it and the first preliminary tests were conducted by Bertrand Lavazais from +GF+ Machining Solutions.

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