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Development of a new generator for electrochemical micro-machining

Nicola GIANDOMENICO[a] *, Olivier MEYLAN[a]

[a]hepia, haute école du paysage, d'ingénierie
et d'architecture de Genève, Member of the HES-SO University of Applied Sciences
and Arts Western Switzerland (HES-SO), Rue de la Prairie 4, CH 1202 Geneva, Switzerland

* Corresponding author. Tel.: +41 22 546 26 39; *E-mail address:* nicola.giandomenico@hesge.ch

Abstract

One of the great advantages in Electrochemical Machining (ECM) is that there is practically no affected zone generated on the machined surface. Also, compared to the electro-discharge machining (EDM), there is no wear on the electrode. Nevertheless, the disadvantage of this process is the relatively poor accuracy, due to the dissolution that occur in the gap, generated by gas bubbles that increase the current density at the side gap. To prevent this drawback, it has been demonstrated that using ultra-short current pulses (100 ns and less) at high frequency (around the MHz), the result is an effective method that improve remarkably the machining accuracy [1]. In order to achieve ultra-short current pulses, the method of electrostatic induction feeding has been used that allows the generation of current pulses shorter than several tens of nano-seconds [1]. This technic is very simple and low cost but suffers from the following inconvenient: the pulse duration and the peak current depends on the size of the electrode (capacitance between the electrode and the machining piece) and on the machining conditions.
The purpose of our development is to reach the same objectives in terms of simplicity and inexpensive generator but with a high flexibility.
By changing peak current and duration, one can adapt very precisely the power and consequently the machining rate and the accuracy, adapting the generator to a multiple kind of applications. Moreover, for stable machining, we have identified and used an electrical signal allowing the process control.

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Keywords: Micro electrochemical machining; ultra short current pulse; high precision micro machining.

1. Introduction

Micro-electrochemical machining (ECM), using the electrostatic induction feeding method, was presented by Koyano et al. [1] at the Seventeenth CIRP conference. With this approach, the hardware needed for the current pulse generation is very simple and inexpensive (Fig 1). Ultra-short pulses of several [ns] can be easily obtained. Machining micro-hole drilling of small gap of 1 [um] has been achieved. In this referred paper, one can find the physical reasons that lead to the need of ultra short current pulses in order to obtain high precision machining, without increasing the current density at the side gap and thus blocking the dissolution.

This technique is efficient and low cost but suffers of some drawbacks. Since the machining gap is electrically equivalent to a resistance (the electrolyte) and a capacitance (the electric double layer formed on the electrode), the pulse duration and the peak current depend on the physical dimensions of the electrode, the value of the added feeding capacitance, the machining conditions and the cabling.

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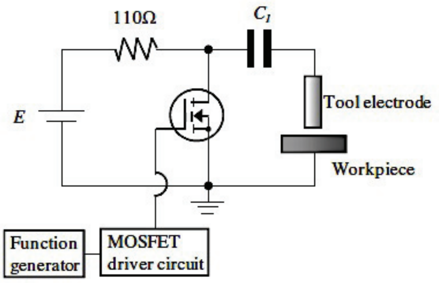

Fig. 1: Electrostatic Induction Feeding ECM (picture from [1])

Moreover, with this topology it is difficult to modify easily the peak value and the pulse duration parameters.

This has driven us to develop a new generator. The purpose has been to reach almost the same objectives in terms of simplicity and inexpensive hardware but with higher flexibility in order to extend the machining possibilities. The duration, from less than tenth to hundreds of [ns] and peak current from tenth to hundreds of [mA], are settable and insensitive to external machining conditions.

This project has been proposed as a bachelor's thesis at hepia [2]. It has been conducted by Olivier Meylan in the electronics laboratory of the hepia/inSTI institute, under the supervision of Professor Nicola Giandomenico.

Nomenclature

gap	Distance between the electrode and the workpiece
FPGA	Field Programmable Gate Array
HMI	Human-machine interface
Labview	Visual programming language and environment

2. Generator specifications

The design specifications of the generator are the following (Fig 2):

- The current pulse duration should be settable from 10 to 500 [ns]
- The current peak should be settable from 10 to 120 [mA]
- The frequency should be settable from 100 to 1250 [kHz]

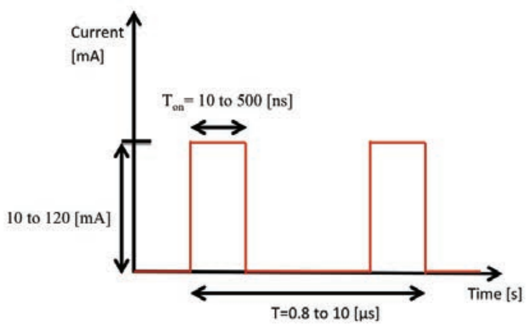

Fig. 2: Current generator requirements

The repeatability of the pulses must be guaranteed in any machining conditions.

All the parameters must be configured and adjusted by the user from a friendly interface, based on the Labview software.

In order to regulate the process of micro-ECM machining, a gap voltage measurement should be added: the average voltage for the regulation and a high-speed detection for the short-circuit detection.

3. Topology of the new generator

During the study, two kinds of topologies have been analysed: one based on a linear concept and the second one using hard switching principle [5].

For different reasons [3], the hard switching has been chosen, based on a standard and inexpensive component basically used as a LED driver, the LT3590 (Fig 3).

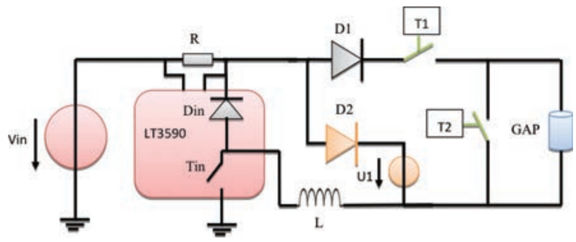

Fig. 3: Generator principle

The regulation of the output current is achieved by the measurement of the voltage across the resistance (R) and compared with an analogue reference set by the user. The current flows through the internal switch (T_{in}) when it is ON and the diode (D_{in}) when OFF. The use of a large inductance (L) value permits to minimize the current ripple.

In all the hard switching topologies using an inductor (L), it is compulsory to ensure that the current is never brutally interrupted.

The concept is the following: when the current is not flowing through the gap, for example because the electrode is out of the electrolyte, the current is driven through the source voltage U_1, simply realised using a Zener diode.

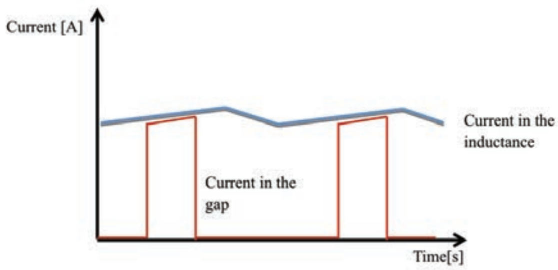

Fig. 4: Gap and inductor currents

Otherwise, in normal machining condition, the current flows through the diode D_1, the switch T_1 and obviously the gap. The two transistors T_1 and T_2 and the associated drivers generate the desired current pulse (Fig 4).

To achieve pulses of very short duration, the MOSFET transistors T_1 and T_2 and their drivers must have high speed switching characteristics. Moreover, an FPGA with 10 [ns] of internal clock manages the trigger sequence.

The LT3590 is limited to 50 [mA] of output current. So to answer the specifications, three same assemblies have been put in parallel in order to achieve 150 [mA].

Finally, an external source (U_{in}) can apply the voltage on the gap in a range of 8 to 40 [V].

4. The complete system

In the figure 5, one can see the whole system composed by: the current generation, the ECM process measurement, the motor control and the user HMI.

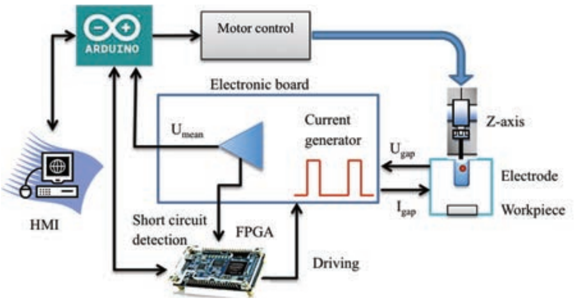

Fig. 5: The whole system

In addition to the main parts presented in the above paragraph, a very simple and low-cost processor platform (Arduino) has been added in order to establish the communication with the PC and implement the algorithm for the process control. Finally, a motor control board drives the Z-axis and the HMI has been developed in Labview.

Fig. 6: Current generator, voltage measurement, FPGA

4.1. The HMI Labview

The box #1 in figure 7 is the control of the Z-axis motor. This module manages the speed, the acceleration and the desired number of steps. A counter calculates the displacement and indicates the position in tenths of micrometres.

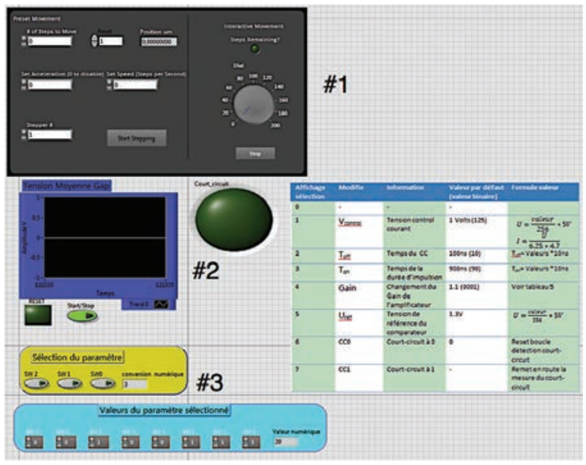

Fig. 7: HMI

The section #2 includes the reading of the average voltage of the gap. This value is shown continuously on the window display. The detection of the short circuit is seen with the big indicator.

The boxes #3 configure the process parameters (peak current, pulse duration and frequency), the reset of all the settings and the start/stop of the machining.

5. Tests on bench

Before evaluating the machining performance, preliminary tests on bench have been conducted to validate the hardware and firmware design.

All the following tests have been performed with a resistance of 56 [Ω]. The resistor has been connected at the end of a cable. This assembly simulates the ECM machining gap and the connection from the generator to the machining area.

As shown in the figures 8, 9 and 10, currents with peak value larger than 100 [mA] have been obtained. Nevertheless, for very short pulses (less than 20 [ns]), the peak current is limited. It is due to the line inductance of the cabling. For improved performance, the generator must be placed very close to the machining area in order to minimize the length of the connection.

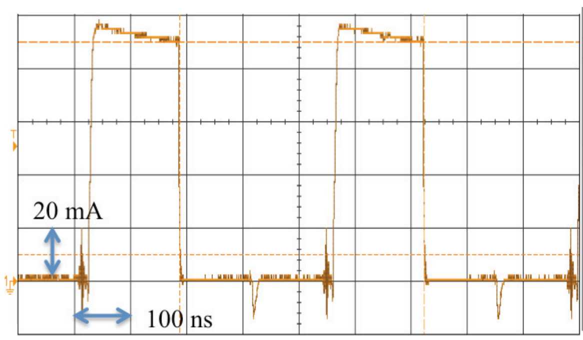

Fig. 8: Output current, configuration 1

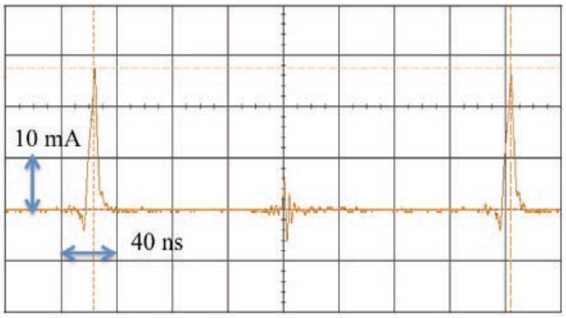

Fig.9: Output current, configuration 2

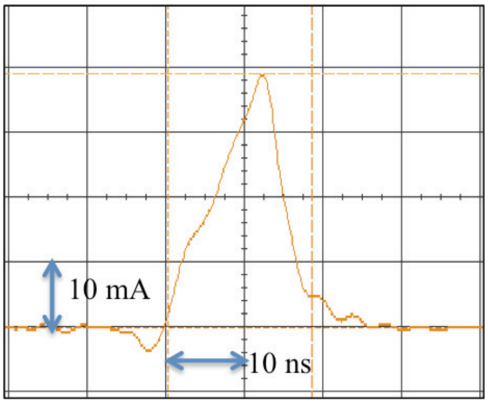

Fig. 10: Output current, zoom of configuration 2

The maximum frequency obtained is better than the specifications, with values close to 4 [MHz].

6. Tests on machine

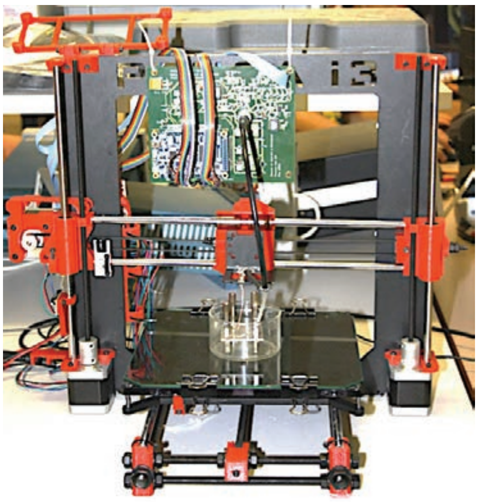

Fig. 11: Prototype machine setup

The first machining tests were carried out on a 3D printer specifically modified in order to fit to our application (Fig 11). The geometric accuracy that can be reached by this machine is limited, but was sufficient to validate our concept. The electrolyte was water with 200g/l of NaNO3 solution.

The purpose of these tests was to make a first hole with a copper electrode of 0.5 [mm] in diameter in an aluminium workpiece and thus validate the forms of the generated current, the control of the servo system and the detection of short circuits.

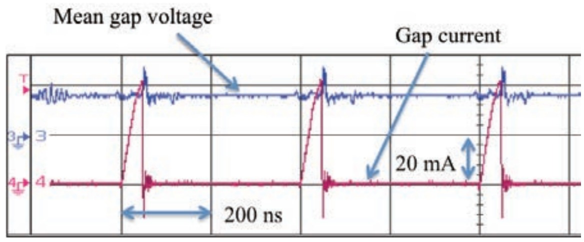

Fig.12: Output current during machining

The figure 13 shows the part after machining in the conditions reported in table 1 and currents depicted in figure 12:

Table 1. Machining configuration

Peak current [mA]	Frequency [kHz]	Current pulse width [ns]	Electrolyte	Duty cycle [-]
40	**2500**	**40**	**water with 200 g/l of NaNO3**	**0.1**

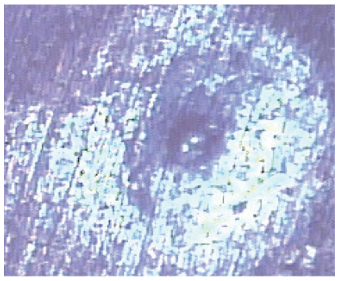

Fig.13: View of the hole with the optical microscope

At the time of the paper redaction, we have been able to achieve a unique machining whose purpose was to functionally validate the hardware and the control system. Performance tests and geometrical measurements of machined parts will be provided during the future bachelor session.

7. Conclusion

This article was mainly focussed on the description of the generator hardware concept.

In this study, micro ECM using a new innovative generator topology, flexible and inexpensive has been conducted. The pulse duration and the peak current can be easily modified. With the measurement of an adequate signal, the complete system can be regulated.

This base platform is highly scalable and will be used in the future by the bachelor students in order to initiate new projects that will focus on achievable machining performance.

In conclusion, the following tasks have been conducted in this primary study:

- Micro ECM machining using a low-cost flexible and innovative current generator topology
- Accurate measurement of the average voltage gap and short-circuit detection
- Easy tuning of pulse duration, frequency and peak current
- Adaptation of a 3D printer machine that host the generator
- Simple HMI interface with process control

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