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EDM 2

THE APPLICATION OF MICRO-COMPUTERS IN CONTROLLING THE SPARK-EROSION PROCESS

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Summary

A description is given of an optimizing system for a spark-erosion die-sinking process with three microcomputers operating in multibusconfiguration. One computer controls the spark-gap, the second one the flushing and the third one operates as an adaptive controller. The adaptive controller adapts the gap-width, the servo gain, the flow-rate and the pulse interval time for optimum process conditions, viz.maximum metal removal rate and minimum electrode wear at a given roughness of the machined workpiece surface.

Introduction

With spark-erosion sinking , apart from the workpiece-tool combination and the properties of the electrical pulses supplied, the properties of the machining process depend on the control of the gap and the flushing between workpiece and electrode.

For a great part the process is characterized by the voltage across the gap, viz. by the nature of the pulses: ignition delay, pulse efficiency and the distribution in time of the effective eroding, arc, open, and short-circuit pulses. The gap width is controlled by a servo system with the process phenomena as sensors.

In non-automatically controlled systems, for optimum machining, a skilled operator has to adjust continuously the machining parameters such as dielectric flow-rate, desired gap width, servo gain and pulse-interval time.

Since the introduction of microprocessors interesting and cheap solutions for improving the process control are possible. At the laboratory for physical machining of the Eindhoven University of Technology an experimental microcomputer controlled spark-erosion die-sinking system has been constructed. Since both hardware and software are of modular design, the system is quite flexible so that various optimizing strategies can be tested.

Description of the system

The experimental spark-erosion system (see Fig.1) consists of:

1. The mechanical system, a revised Nassovia spark-erosion machine with an electro-hydraulic servo system.
2. A dielectric system, with pump, filtering and measuring unit.
3. An electrical system, consisting of a digital pulse generator, power amplifier, servo drive-amplifier and safety system.
4. An electronic control system, consisting of a pulse-voltage conditioner and analyzer and three microcomputers. One computer controls the servo valve, another the dielectric flow-rate and the third, the main microcomputer, operates as the adaptive controller of the entire system.

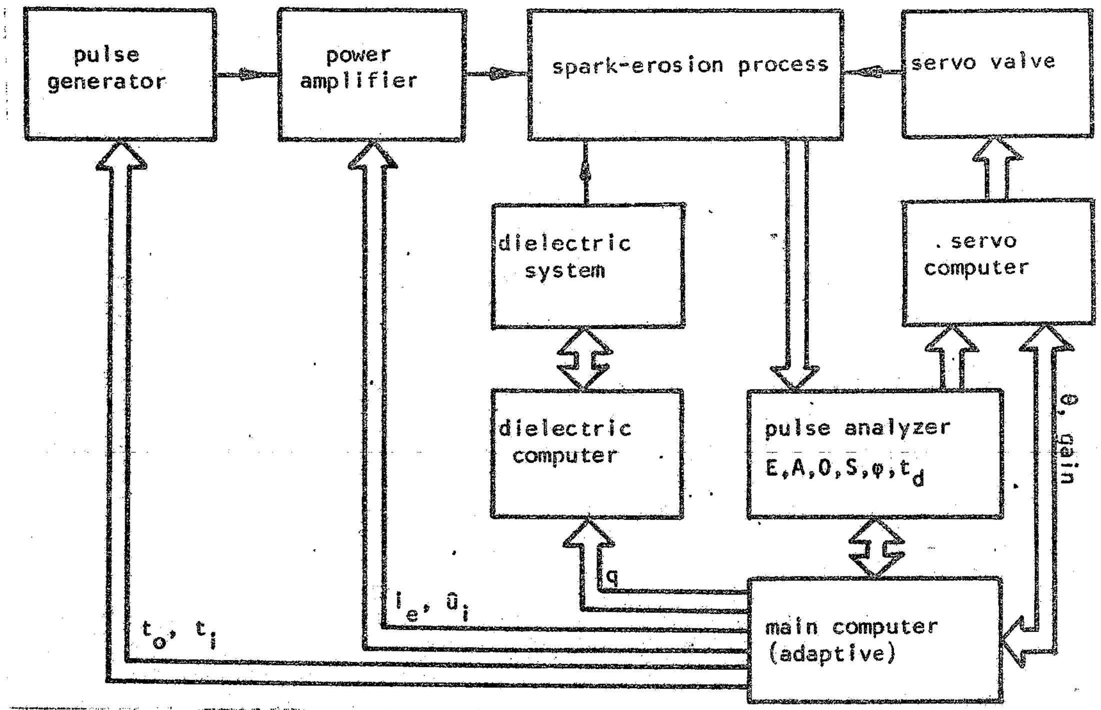
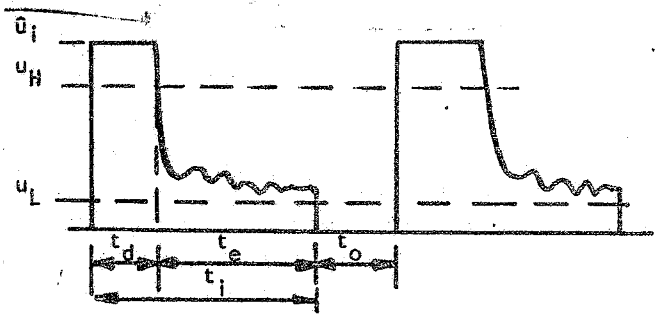


Fig. 1. The entire computer controlled spark-erosion system.

The response time-constant of the electro-hydraulic servo actuator is approximately 2 ms, the effective stroke is 6 mm, so the complete servo system needs an additional long-stroke actuator. This actuator has an ordinary d.c. motor and a stroke of 30 cm. The dielectric system has a flow-rate range of $q = 0.2 - 200\ \mathrm{cm}^3/\mathrm{s}$ and is digitally controllable (10 bit) by an INTEL SBC80/04 single board microcomputer. The output pressure can be maximally 0.5 MPa. The pulse durations (t_i) and the pulse interval times (t_o) can range from 1 μs up to 999 μs in 1 μs steps. The generator supplies the pulses to the power amplifier which can deliver energy to the spark-gap with currents (i_e) ranging from 1 A up to 65 A in 1 A steps. The open pulse voltage ($\hat{u}_i$) can be either 80 V or 250 V.



$$\varphi = \frac{t_{en}}{t_i} \quad \text{(only erosion pulses)}$$

$$\bar{\varphi} = \frac{\Sigma t_{en}}{\Sigma t_i}$$

$$\bar{t}_d = \frac{1}{n}\,\Sigma\, t_d \quad \text{(n= number of pulses)}$$

	u(during t_i)	t_d	t_e
erosion	$>u_L$	> 50 ns	t_{en}
arc	$>u_L$	< 50 ns	t_{ea}
open	$>u_H$	$= t_i$	o
short-circuit	$<u_L$ at any time	-	o

Fig. 2. Classification of the pulses and definitions of $\bar{\varphi}$ and $\bar{t}_d$.

The pulse conditioner and the analyzer classify the pulses at the gap in erosion-pulses (E), arc-pulses (A), open-pulses (0) and short-circuit pulses (S). Further, of each pulse the pulse efficiency $\varphi = \frac{t_{en}}{t_i}$ and the ignition delay t_d is measured. Pulses down to $t_i = t_o = 1$ µs can be analyzed. Since the measuring time is too short for a microprocessor, the pulse analyzer has been designed in hardware. The digital output is available at an 8 bit output bus for the microcomputers. Fig. 2 shows the pulse classification. In order to drive the servo valve correctly, the sample time of the servocontroller must be at least 4 times as short as the servo response time. 480 µs is choosen as longest sample time, what means that the servocomputer has to compute and to supply new information to the servo valve each 480 µs. If the pulse repetition time $t_p(=t_i+t_o)$ is much shorter than 480 µs, the pulse analyzer classifies and measures n pulses. The number of n is a power of 2 and will be calculated by the main computer in such a way that the sample time will be between 240 µs and 480 µs.

The servo microcomputer (INTEL SBC 80/20-04) acts as the controller part of the servo loop. The main sensor of the servo loop is the average ignition delay $\bar{t}_d$, measured over n pulses by the analyzer. This (16 bit) information is compared with the value θ which represents the desired gap width between workpiece and electrode. The value θ, the servo gain of the servo loop and special nonlinear servo programmes are controlled by the main computer via the multibus on interrupt basis.

The main microcomputer (INTEL SBC 80/20-4) controls the entire system. Its functions are:
- adaptive controller of the spark-erosion process;
- driver for the periphery equipment such as key-board and video-display in order to enable the operator to supervise the system and a paper tape puncher for data collection in order to analyze the process on a large computer system.

The input data of the main computer are:
- results of the pulse classification (E,A,O,S) during n pulses (8 bit);
- the values of the average ignition delay ($\bar{t}_d$, 16 bit) and the average pulse efficiency ($\bar{\varphi}$, 8 bit);
- data from the key-board;
- acknowledgement signals from the two other computers.

The output data are:
- values for the desired gap-width θ and gain for the servo microcomputer;
- command data for the nonlinear servo programmes;
- values for pulse duration t_i, pulse interval time t_o, pulse voltage $\hat{u}_i$ and pulse current i_e to the pulse generator;
- value for the flow rate q to the dielectric computer;
- interrupt signals to the slave computers;
- data to the video-display.

The initial values for the pulse duration, pulse interval time, pulse current and pulse voltage are entered by means of the key-board. Next, the operator can choose either automatic or manual process control. After starting the process the percentage of the erosion, arc, open, and short-circuit pulses are displayed, together with the values of the average pulse efficiency and ignition delay. New values are displayed approximately each second.

The control strategy

The control strategy is based on maximizing the metal removal rate together with minimizing the relative electrode wear at a given roughness of the workpiece to be machined. The roughness is assumed to be determined by the pulse duration and the pulse current at a given polarity and workpiece-tool material combination. However, if these parameters are given both the metal removal rate and the relative wear are more or less fixed provided a number of other conditions are fulfilled. These conditions are: minimizing the pulse interval time t_o, maximizing the pulse efficiency φ, maximizing the percentage of effective erosion pulses E, correct gap width and stable servo operation. Stable servo operation is defined as the minimizing of the sum of the squares of the differences of the values of the desired gap-width θ and the ignition delay t_d, representing the actual gap-width. This sum is taken over a large number of pulses. Unstable operation will occur when t_o is too small or the flushing is incorrect. Also, too small a gap width can cause unstable operation due to the increase in short-circuit pulses and arc-pulses. The increase in the percentage of short-circuit and arc-pulses often influences the relative wear and the metal removal rate negatively. Local piling up of contamination of the dielectric fluid in the gap often causes an apparent small gap-width and so instability.

In the adaptive control programme is one routine for finding the maximum value of the pulse efficiency φ. In this routine the value of the desired gap-width θ and the pulse interval time t_0 are alternatively changed. This is done by means of a direct search hill-climbing method. In the second routine the servo loop stability is controlled by changing the servo gain.

After switching on the automatic process control, the main computer calculates starting values for θ, gain and q. Then the computer calculates new values for these variables and for t_0 every 2048 * n pulses. During this period, when too many arc-pulses occur, special servo programmes are entered into the slave computer which results in lifting the electrode, increasing the flow-rate and decreasing the pulse current. Also, when during a short period, e.g. n pulses, the percentage short-circuit pulses is too high, the servo computer will jump to another non-linear programme. In this case the electrode will lift rapidly and return slowly when the short-circuit is over. The current will be decreased during the short circuit. The interrupt programmes will be switched on when the machining conditions become difficult, e.g. with deep holes, large machining surfaces with difficult flushing, and when a hole is piercing the workpiece.

Programming

The computers are programmed in their symbolic machine language with the aid of a macro assembler (ISIS). The programme is of modular construction with subroutines. After individual testing of these routines they are copied in EPROM. The development of the software took approximately 1000 man-hours.

Conclusion

Experiments have proved that the automatic control system operates satisfactorily. After switching on the equipment, the system moves towards its optimum machining condition. With a pulse duration of 100 µs, pulse current of 25 A, a steel workpiece and circular copper electrode of 20 mm in diameter with central flushing, the controller decreases the pulse interval time to approximately 5 µs and the average ignition delay to 7-10 µs. In this case the eroding circumstances were not difficult. However, when the hole became deeper, the pulse interval time increased and more lifting periods of the electrode occurred.

Experiments with the servo short-circuit programme show that the movement of the electrode is very important to the flushing conditions and influences the geometrical electrode wear.

Another subject of investigation is the further development of the adaptive controller. The controller described is of the type of model reference. However, since the process is very stochastic a minimum variancy self-tuning regulator could be effective. Investigations in these fields are in progress.