An Open Numerical Control Architecture for Electro-Discharge Machining[1]

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Abstract

Numerical control (NC) systems are opening wide fields of application for ED machining. An operation along a 3-D course makes possible to produce a very complex geometry with a simple tool electrode and ED machining turns into a shaping technique. A standard NC system can not be used for control operations in ED machines because of substantial differences resulting from the nature of the process. Therefore special requirements of ED process towards a numerical control have been acquired in order to develop a specified numerical control for EDM. Disadvantageous in the use of non-standard numerical controllers like those used in EDM are limitations in the information exchange with other automation systems. Vendor specific interfaces and a lack of transparency in the implementation often originate these problem. The objective of the OSACA standard is to define a reference architecture for numerical controllers, in order to achieve an extendible system without vendor restrictions. The developed numerical control for EDM applications is designed to follow the architecture defined by OSACA closely to provide the benefits of this standard for ED-machining.

Key Words: *electro-discharge machining (EDM); numerical control; open systems*

1. Numerical Controllers for Electro-Discharge Machining

In pure sinking electro-discharge (ED) machining the electrode moves straight into the workpiece. By using more than one axis, improvements in the application of EDM can be achieved [1]. A circular movement (planetary erosion), overlaid to the sinking operation, improves the flushing conditions and permits a stable removal process even at difficult geometrical gap conditions [2]. Furthermore with planetary erosion there is no need to construct a roughing electrode with smaller dimensions. Electrodes of the same size can be used for roughing as well as for finishing. Even a complex geometry can be generated, if the ED-operation is carried out along a 3-D course [3]. The numerical control (NC) systems employed in ED-machines differs much from standard NC systems.

Generator-, impulse-, gap-width-controller-signals as well as flushing parameters have to be adjusted by data-records to the NC data input facilities. The electrode movement must be handled by a gap-width-controller. Therefore the spindle motion is not straight forward, but oscillating along the complex 3D tool path. Flushing movements are needed as reaction to sudden process corruption, they require a defined strategy for backward movements. The user-interface must provide extensive technological knowledge to the operator. Therefore ED machining needs a specific NC.

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2. CONVENTIONAL NUMERICAL CONTROL

A standard numerical control (NC) can be portioned in three main functional units [4]:

1. Human-machine interface:
   This unit is responsible for communication between the human operator and the NC.
2. NC-data processing and administration:
   Here informations are extracted from the input NC-data and provided for further processing.
3. Geometrical data processing:
   The purpose of this unit is to control the motion of the machine axis.

Other functional units might be added e.g. for diagnosis, but are not of importance here.

As essential part for generation and execution of axis motion the geometrical data processing will be explained more detailed in the following. The data flow of this functional unit can be seen in figure 1.

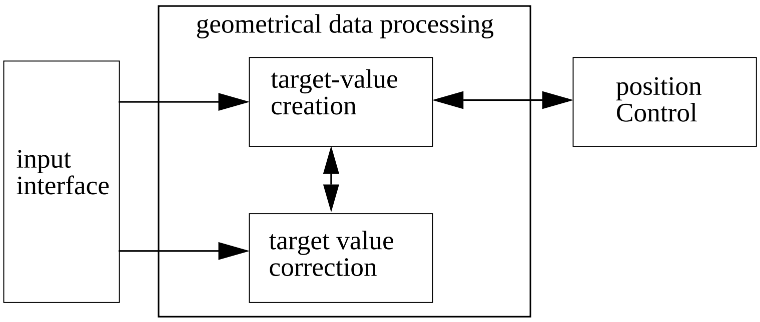

Figure 1: Simplified data flow in geometrical data processing unit

The „target value creation“ is responsible for the calculation of points along the specified course by interpolation according to the chosen figure type (line, circle, spline etc.).

The „target value correction“ has several tasks:

- Limitation of the acceleration to avoid deviations from the target course.
- Detection of the moment (T_B) when slow down should start (see figure 2).
- Compensation of the rest of the path at the end of a NC data set after slowing down.

The speed along the programmed course (feed rate) is constant and provided by the user. The maximum acceleration that each axis can handle is known from the machine specific data. Therefore it is possible to calculate a speed profile as shown in figure 2 for each NC data-set [5].

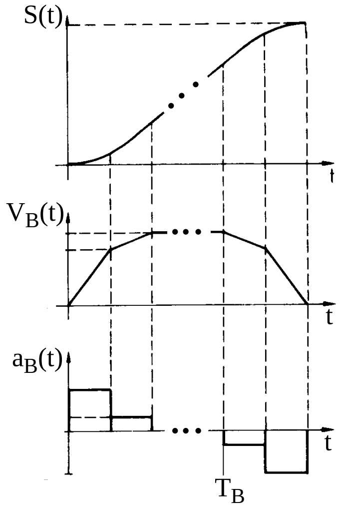

Figure 2: Speed progression when using a two step acceleration

Because of the predefined speed progression the interpolator of the course can calculate a fixed increment for the permanent change of target position.

Extensions are needed to avoid falsification of the programmed course when axis speed changes drastically. This is done very often by looking in advance to several NC data sets in order to react if sudden changes in axis speed will appear (look ahead strategy).

3. ARCHITECTURE OF A NUMERICAL CONTROL FOR EDM

In EDM the feed rate can not be defined by the user. The electrode speed is determined by the process. In case of open-circuits the electrode must be moved forward along the programmed course. In contrast short circuits demand a backward movement. Therefore a gap-width controller must be integrated (figure 3) to adapt the feed rate according to the process situation. NC-concepts based on a constant velocity movement along a wide part of the course cannot be used [6].

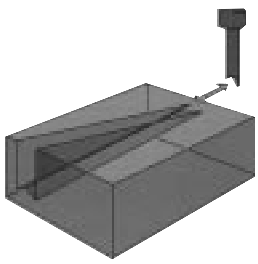

Figure 3: ED-processing of a line in 3D

Figure 4 shows the data-flow inside of the developed EDM-NC system. The target feed rate (V_B) is computed by the gap-width controller based on an actual evaluation of the ED-process. V_B is valid only for one NC sample-time (T). Next step in calculation is the check of the target feed rate. In case of exceeding the maximal admitted acceleration a correction of the feed rate is made to avoid a deviation of the target course. Based on this proven feed-rate (V'_B) the increment along the course (Δs) is calculated and the interpolation can generate new target positions (X_T, Y_T, Z_T) for the drives.

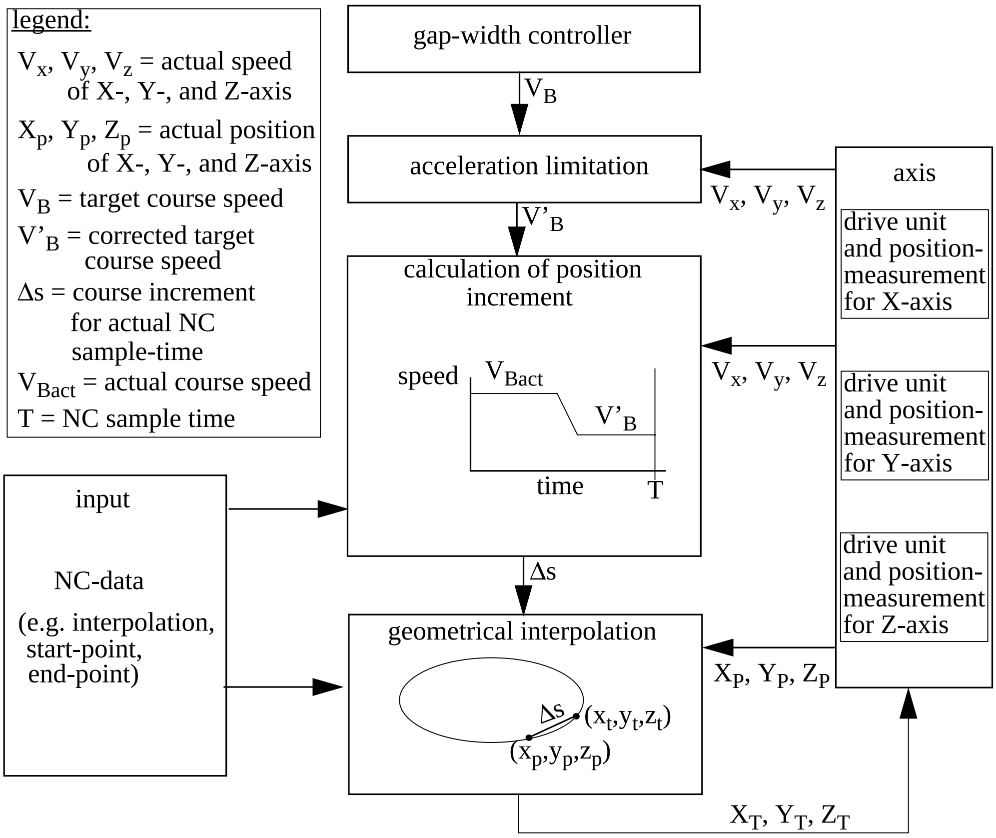

Figure 4: Data-flow for the developed EDM-NC

With this concept even backward movements along the 3D-course can be handled. Because of the low path velocity at EDM processes there is no need to implement a „lock ahead strategy“.

Another problem arises in the situation if just after finishing one NC-data set a short circuit is detected. This requires the release of a control motion in the form of a backward move of the electrode. This must be performed along the course defined by the previous NC-data set (figure 5).

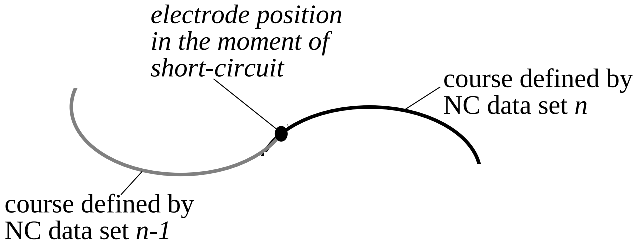

Figure 5: Short circuit situation immediately after beginning a new NC data set

To handle this situation the electrode has to be moved backward along the course defined by the previous NC data set. Therefore it must be possible to switch back to the last NC data-set. This „look back“ strategy needs extra effort in the control flow.

Beside normal EDM operation the execution of flushing movements must be implemented inside of the NC-system. Caused by sudden tendencies toward process corruption a programmed flushing strategy must be carried out, in order to clean the gap from removed particles. In the developed NC system flushing strategy consisting of an oscillating and lift-up movement is implemented [7]. Other strategies can easily be added.

Beside extensions inside of the geometrical data processing other parts of the NC system must be modified, too. To enable ED-machining the user-interface must provide extensive technological knowledge to the operator. Additional modules are needed to access external hardware devices like generator or external flushing unit.

4. HARDWARE OF THE EDM NC SYSTEM

The hardware of the developed EDM-NC is based on a VMEbus computer system [8]. The NC-software is executed from a CPU-board (PowerPC) running the real-time operating system VxWorks [9]. All external devices are addressed by commercial field-bus adapter boards (figure 6):

- The drives are connected by a Sercos optical fiber ring [10].
- The generator is programmed using a CAN-fieldbus.
- A second CAN fieldbus running a much higher transfer rate is used to connect the gap-sensor. This data link transfers the real-time data measured during ED-processing (ignition-delay time (t_d), number of arcs, open- and short circuits) for further processing to the gap-width controller.
- A control logic (Simatic S7) handles the peripheral units of the machine (pumps, tank, etc.) [11]. It is connected by a RS-422 interface to the VMEbus system.

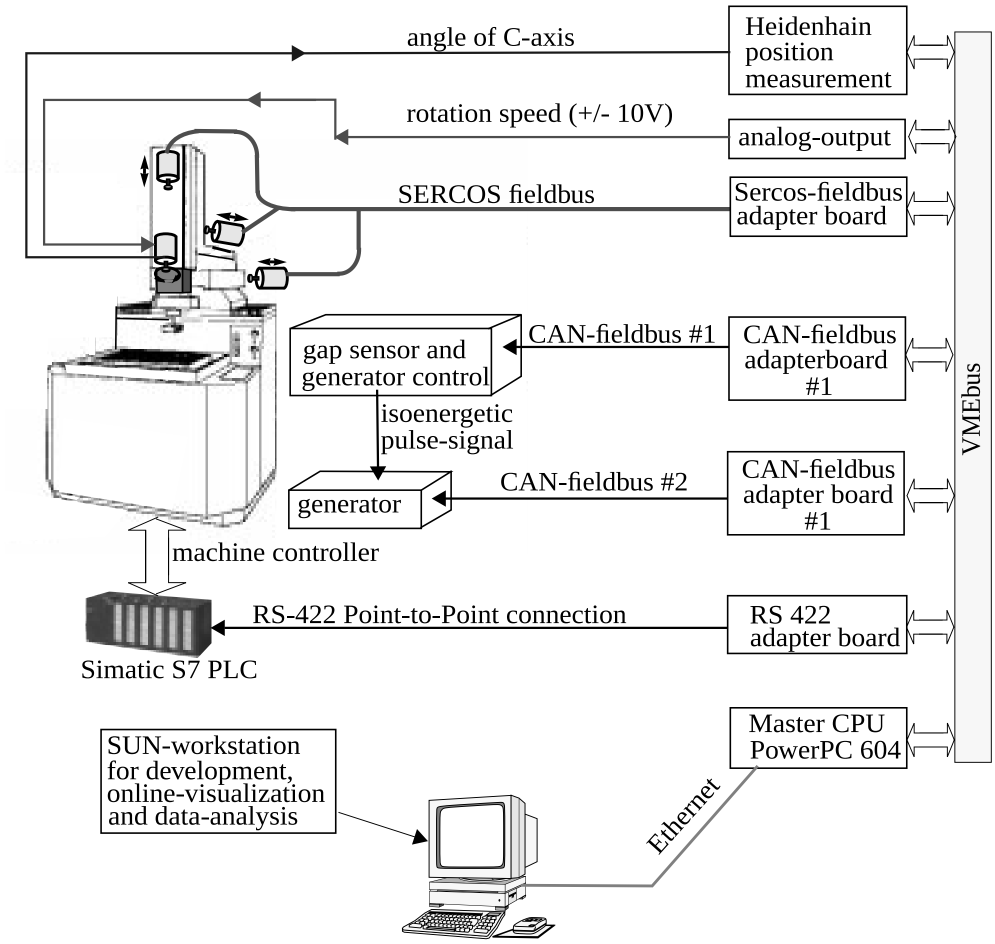

Figure 6: Hardware of the experimental EDM control system

The interface between the ED-process and the NC-system (gap-width controller) is implemented by the „gap sensor and generator control“. This unit provides several functions:

- Isoenergetic generator-pulse creation.
- Arc detection and suppression.
- Detection and reaction to open-circuits and short-circuits.
- Measurement of ignition-delay time (t_d).
- Filtering of process data.
- Recording of process data.
- Communication with VMEbus-system (by CAN-fieldbus)

The gap-sensor is implemented using FPGA-technology [12] (field programmable gate array), thus measurement and timing tasks can be done with a resolution of 50ns. The CAN interface provides high flexibility in NC-system hardware selection, because this sensor can be combined with any system providing such an interface.

5. OSACA

In order to reduce production time and increase quality the optimal planing and controlling of manufacturing processes is of great importance. Information distribution and handling became one of the key functions for optimal controlling [13]. One essential aim therefore is to achieve a computerized connection of the greatest possible number of production facilities [14].

Non-standard control systems often handicap this information exchange by their lack of open interfaces [15]. Therefore in Europe the Open Systems Architecture for Controls within Automation Systems (OSACA) has been developed in order to solve these problems [16].

OSACA defines a common, vendor neutral application programming interface (API) for control applications [17]. There is a complete separation of the application and the hardware/operating system. Furthermore OSACA avoids dependencies between control functions and their distribution to different hardware platforms. To provide exchangeability and extensibility OSACA defines guidelines for the architecture of a control application. Each application has to be portioned into functional units. These units have to be assigned to so-called architecture objects (AO). A communication mechanism is responsible for the data exchange between the different AO's.

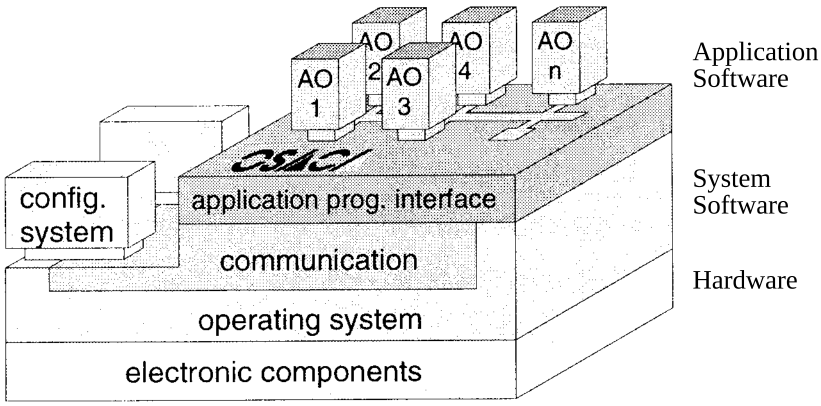

Figure 7: Layout of the OSACA system platform [18]

The main components of the OSACA system platform are (figure 7):

- The configuration system: Builds up the Application at starting time by connecting the different AO's [19].
- The communication facility: Provides operating system and hardware independent communication services between different AO's by using a common interface [20].
- The reference architecture: Defines the architecture objects (AO's) that have to be implemented inside of a numerical control together with their interfaces.

control application by using standard components. So the problems resulting from the non-open interfaces of ED-specific controllers can be solved.

The architecture of the developed NC-system for ED-machining is oriented towards the OSACA reference architecture. Additional units for ED-specific tasks has been added:

- Generator-management:For setting pulse parameters and diagnostic purposes.
- Gap-Sensor interface:To obtain and filter process data from the gap sensor.
- Flushing controller:Flushing movements are carried out by the unit.

Other architecture objects, which correspond to AO's defined by the OSACA reference architecture, must be specialized for use inside of the EDM-NC (e.g. interpolation).

6. EXPERIMENTS AND RESULTS

The resulting NC-system is able to control the ED-process in a 3-axis machine configuration. Courses in 3D can be interpolated by the developed EDM-NC. Also planetary strategies are implemented by the NC system. Figure 8 and figure 9 show different experiments carried out using a spiral and a star-shaped motion.

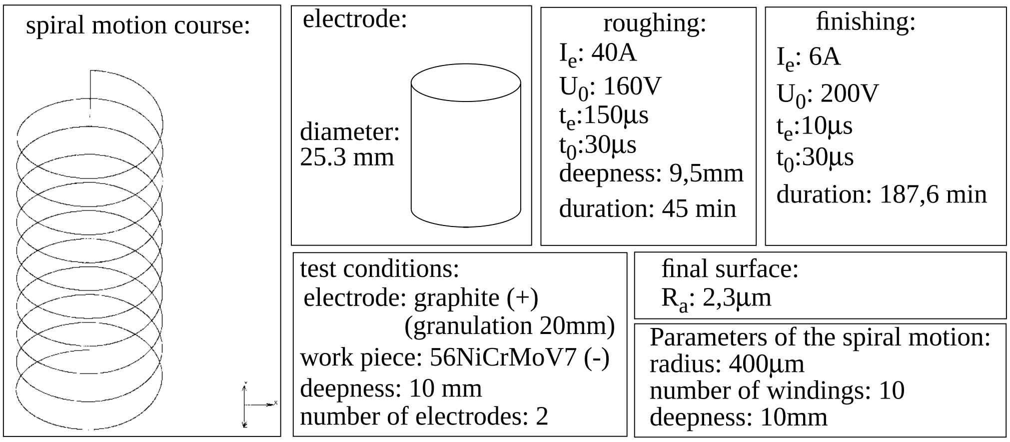

Figure 8: ED application using spiral motion strategy

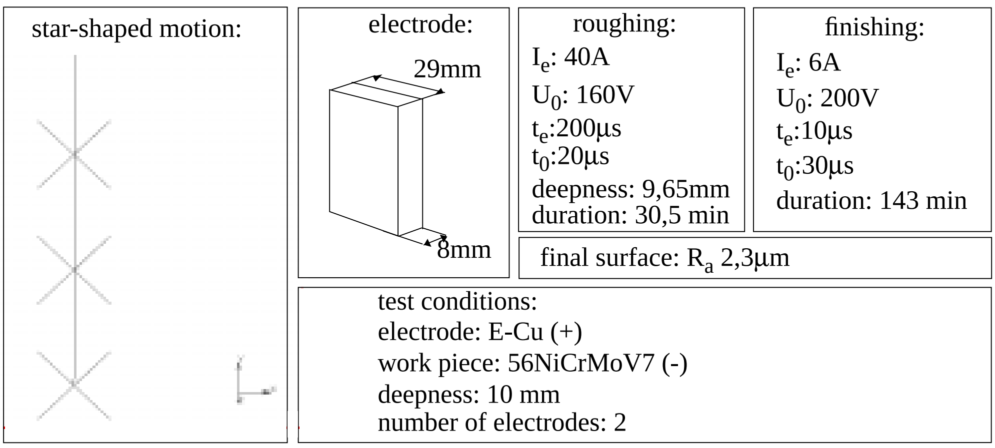

Figure 9: ED-application using star-shaped motion

BIBLIOGRAPHY

[1] W. König: „*Fertigungsverfahren; Band 3 - Abtragen*“, VDI-Verlag, Düsseldorf, 1990

[2] M. Slomka: „*Funkenerosives Senken - adaptive Vorschubregelung und Planetärbewegung*“, Dissertation, RWTH Aachen, 1989

[3] N.N.: „*Robofil, Roboform*“, Charmilles Technologies S.A., Genf, 1986

[4] B. Walker: „*Konfigurierbarer Funktionsblock Geometriedatenverarbeitung für numerische Steuerungen*“, Springer-Verlag, Berlin, Dissertation Universität Stuttgart, 1987

[5] D. Binder: „*Untersuchungen zur Interpolation in numerischen Steuerungen*“, Berlin, Springer-Verlag, Dissertation Universität Stuttgart, 1979

[6] M. Weck.:„*Werkzeugmaschinen; Band 3 - Automatisierung und Steuerungstechnik*“, VDI-Verlag, Düsseldorf, 1989

[7] M. P. Witzak: „*Verbesserung der Prozeßführungssysteme für funkenerosive Senkanlagen unter Einbeziehung von Fuzzy-Technologien*“, Dissertation, Universität der Bundeswehr Hamburg, 1997

[8] N.N.:„*The VMEbus Handbook - A User’s guide to the IEEE 1014 and IEC 821 microcomputer bus*“, VITA, Scottsdale, USA, 1993

[9] N.N.:„*VxWorks - Reference Manual*“, Wind River Systems, Alamede, USA, 1999

[10] N.N.: „*SERCOS Interface Controller - Reference Manual*“, IAM, Braunschweig, 1993

[11] N.N.: „*SIMATIC Software - Basissoftware für S7 und M7*“, Siemens AG, Nürnberg, 1996

[12] N.N.: „*XC4000E and XC4000X Series Field Programmable Gate Arrays*“, Xilinx, San Jose, USA, 1999

[13] H.-J. Thon: „*Netzwerke zur industriellen Kommunikation*“, in: Proc. „*Systemtechnik - ein Instrument zur Unternehmensführung*“, Bayerischer Forschungsverbund Systemtechnik 1991

[14] W. Blöchl: „*Erweiterte Informationsbereitstellung an offenen CNC-Steuerungen zur Prozeß- und Programmoptimierung*“, Dissertation FAU Erlangen, 1997

[15] M. Weck; A. Kohring; F. Klein: „*Offene NC-Systeme, Grundlage herstellerunabhängiger Flexibilität*“, VDI-Z 135, Nr. 5, 1993, S. 51 - 55

[16] N.N.: „*OSACA I und II: Final Report*“, FISW GmbH, Stuttgart 1996

[17] W. Sperling: „*Modulare Systemplattformen für offene Steuerungssysteme*“, Springer-Verlag, Berlin, Dissertation Universität Stuttgart, 1999

[18] N.N.: „*OSACA Handbook*“, IDAS-OSACA Consortium, Stuttgart, 1997

[19] C. Daniel: „*Dynamisches Konfigurieren von Steuerungssoftware für offene Systeme*“, Springer-Verlag, Berlin, Dissertation Universität Stuttgart, 1996

[20] W. Kugler: „*Kommunikationsmechanismen für offene Numerische Steuerungssysteme*“, Springer-Verlag, Berlin, Dissertation Universität Stuttgart, 1994