ELMATECH GMBH
electronics machines technologies

Whitepaper

Process Control
Virtual Machine (VM)

for the control of complex processes in the fields

- Manual and automated spot welding
- Manual and automated arc welding
- Automated thermal coating
  (Arc wire spraying, plasma coating i.a.)

Abstract

This white paper explains the benefits of general process control *Virtual Machine* (VM), which is used in machines and systems of ELMA-Tech GmbH.

In three essential areas of application, this control technology achieves absolutely high-quality results which, to the best of our knowledge, can not be achieved with competitive technologies:

- **Scope of application *spot welding***
  Fully automatic spot welding without any previous parameter settings by the user.

- **Scope of application *arc welding***
  The **DC-pulse** welding process basically offers the possibility of very high process speeds with all the advantages of DC pulse technology.

  Best welding results and process characteristics in the welding process **AC-pulse** (AC welding) in the range of thermosensitive materials by lowest energy inputs.
  (ELMA-Tech process name: COLD ELMARC).

- **Scope of application *arc wire spraying***
  Instead of using a fixed and unchangeable characteristics set, ELMA-Tech power sources use entirely free changeable current / voltage curves. Hereby the flexible adjustment of spray parameters for optimized adhesion and extremely fine spray structure is possible, leading to coatings of high quality and overall high coverages.

Situation

Stochastic events - a requirement for the control of complex processes

All welding processes as well as processes of thermal spraying of any kind, whether hand-held or robot-controlled, must be controlled very precisely and flexibly.

Physical parameters, e.g. the material type of the materials to be welded, material thicknesses, current, voltage, wire feed, electrode forces, coating thicknesses, addiditves, process gas flow and time have to be optimally matched in different applications and also different welding technologies.

For example, in arc wire spraying the requirements vary up to an extremely individual and fine process management. At the same time, the exact reproducibility of these complex processes (process reliability) must be ensured in industrial applications.

The problem of controlling such process types

Controlling the physical quantities occurring in these processes, such as current and voltage of an electronic generator, is difficult because they are not exactly deterministic due to the complexity or degrees of freedom of the process - they are therefore stochastic (random) events in a certain context.

Process control with fixed characteristic curves only yields average values in the best case and can not react to stochastic changes in individual process phases. One could say that fixed characteristic curves do not allow „sensitive“ and customizable management of processes.

Solution

A detailed explanation of the *Virtual Machine* can not be made here. Roughly simplifying, one can say:

The individual process states during welding or thermal spraying are subdivided into discrete time units or segments. One basic idea is to be able to segment a process with start and end into individual areas (start, stationary area, exit), another to be able to react within a segment to process peculiarities with replacement of the generator characteristics as soon as possible.

By means of a computer system, those parameters which define the static and dynamic generator behavior are to be exchanged as often and as quickly as possible, so that a generator can be provided, which is optimally suitable for identifiable process phases.

This subdivision process into smallest time units is repeated according to the requirements of the respective welding task until the completion of the welding operation.

The static and dynamic control implemented in the *Virtual Machine* evaluates these rapidly changing process states. These are processes that take place in the thousandths of a second range. The Virtual Machine responds to any different condition within the range of its cycle frequency of 20 kHz, that is within 50 microseconds.

The limit of the reaction time of 50µs already results from the technical possibilities to enforce modified action of the generator over connecting lines to the process. Each line between generator and sink (process) has inductive components that do not require a higher rotational speed of the slave processor, as an enforcement above 10 kHz can not succeed anyway.

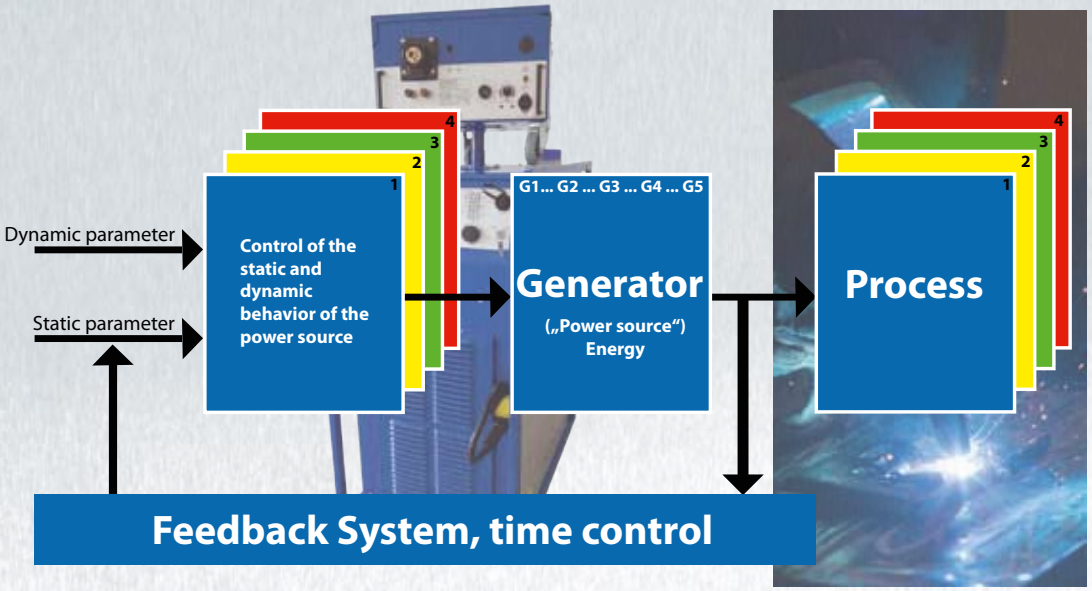
With such a structure, not only the generator character of the power source can be redefined, but also all other and peripheral controls e.g. of servo valves in welding guns or wire feeds in arc processes can be carried out.

Advantages of *Virtual Machine* (VM) controlled generators

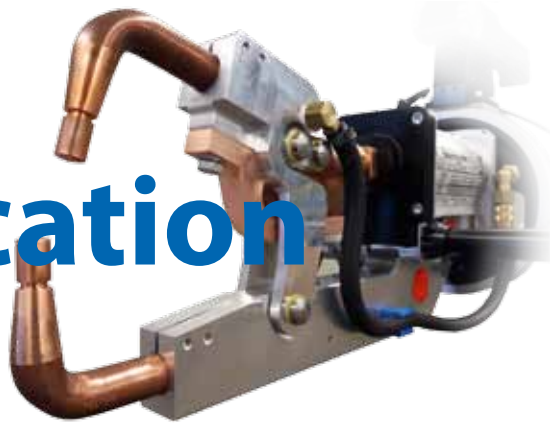
In contrast to conventional generators with design-specific static and dynamic characteristics, electronic generators can be optimally designed in their current character, depending on the current process phase or the current process state, and in accordance with the growing process understanding.

Parameters required for this are part of a database, in which these are fed in as growing expert knowledge. Through the operation of the administrator computer of the VM, these parameters are made available to the program vector (the slave computer of the VM) for execution.

Schematic representation of the principle of process control Virtual Machine



For each different status of the process, a special generator is adjusted, realized by means of a specific static and dynamic behavior of this generator. The parameters required for this purpose are derived from a database in which these parameters have been stored as growing expert knowledge (welding programs).



Scope of application

Spot welding

In 2008, after several years of development cooperation with Opel, ELMA-Tech presents the first spot welding machine with fully automatic control of the spot welding process. The series of these machines or spot welding guns receive the suffix „VISION“ as of this date.

Two significant developments lead to this type of control, which is still unique on the world market:

- The development of process control *Virtual Machine* (VM)
- The development of a measuring system that allows to virtually measure physical parameters directly at the electrode cap tops of spot welding guns

The process model processed by the *Virtual Machine* has four distinct tasks to perform a high quality spot weld:

- Test of initial state through targeted energy input. Distinction between total-, partial isolation and ideal initial conditions. Detection of total thickness and steel type.
- Induce an initial "first-spot" by introducing a specific energy input. E.g. in case of a partial isolation, which is one of most common cases, the introduction of a specific energy input will cause the workpieces to join more easily.
- Carrying out the actual welding process (current-time program). Here the applied energy amount is continuously added up so that the welding process will end when the machine reaches the desired value.
- Determination of shunts etc. and compensation of possibly lost energy in the welding spot.

The *Virtual Machine* thus recognizes the condition of the parts to be welded, in particular whether there are shunts through structural adhesives, oxidation, paint residues or other contaminants and adjusts the program accordingly to ensure a reproducible high quality spot weld..

Advantages

Plug & Weld

- No parameter setting required anymore:
  Automatic regulation of energy input
- Automatic sheet thickness detection
- Automatic material detection
- Automatic shunt detection
- Automatic energy tracking

- No preparation of welding samples required in advance

- Detecting and welding high-strength steels

- Welding different materials without parameter setting in one welding process

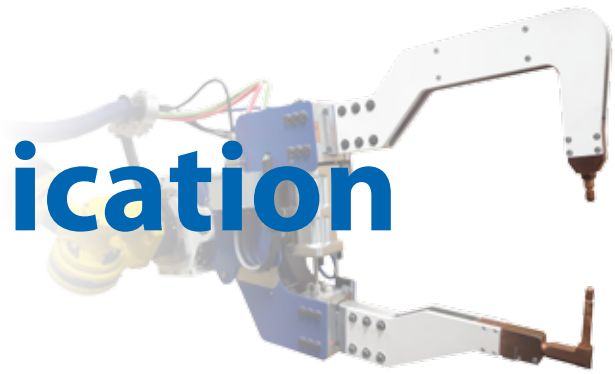
- Weld easily up to 10 mm total sheet thickness

- Aluminum welding of thin sheets up to 3 mm (body repair)

- Effective use of energy (as much energy as necessary for an optimal result)

- Welding parameter storage and quality assurance in spot welding
  With the SpotQS Viewer software, welding parameters of vehicle-specific spot welding connections are recorded and evaluated. The parameters and the welding result can be written to a USB stick after completing a welding task.

Detailed information on the operation of the VISION automatic mode can be found on our website:
https://www.elmatech-gmbh.de/index.php/en/elma-tech-range-of-services/elma-tech-control-technology/automatic-mode-vision



Scope of application

Automated spot welding

Unique automatic system, in which the robot positions the welding gun in place of the point to be welded and then gives the full responsibility to the gun and the welding control (*Virtual Machine*). The control performs the following steps:

- Closing the gun's arms with automatic balancing (float operation)
- Force build-up and detection of the overall sheet thickness
- Calculation of the point energy to be applied
- Starting the welding process with a phase-dependent generator characteristic
- Energy-guided welding process and terminating the process with the calculated spot energy
- Determination of steel quality (normal / high strength)
- Reheating according to the determined steel quality
- Qualification of the course of the process
- Opening of the clamp (7th axis function)
- Disable the gun's balance
- Output of the accelerating contact FK to the robot

Simplest robot programming through handshake between robot and VM control!

So far, the main and compensating cylinder have been controlled by the robot and the power by the welding control. For this purpose, these systems needed to be linked with their own control components with one another via the robot.

Such cross-linking does not apply to the ELMA-Tech control *Virtual Machine* (VM) with full automation for the welding process and the gun offset.

The ELMATECH control with VM takes holistically the function control of all gun components, this includes the measuring techniques for detecting the total sheet thickness, the electrical process control, stroke and force control of the master cylinder and the balance control of the compensating cylinder.

For this main and compensating cylinder were equipped with measurement systems, so that both cylinders together with the control form pneumatic servo systems. This means precise positioning before and after welding in the shortest possible time for the master cylinder. There is no longer a forward stroke by special mechanical design of the master cylinder. The cylinder thus has become very easy and safe to operate.

Scope of application

Arc welding

The core of the technology is the freely controllable power source via the *Virtual Machine* (VM). This power source has essentially the following features:

- The characteristic of the current source (current or voltage source) can be freely selected depending on the process state and changed with a frequency of 20 kHz. This is made possible by an advanced design of the power source, which has no conventional resistors, but only simulates these corresponding to the shape of the current and voltage characteristics.

- The *Virtual Machine* is the control of the power source. The VM recalculates the state of the welding process every 50 µs from the available process parameters and sets the current source characteristic to optimum parameters for this process state.

General benefits

- While conventional power sources usually have fixed values for their internal electrical resistances and inductances, the ELMA-Tech power source can assume any desired values. Thus, the process can be performed optimally at any time, whereas there is only one real optimal operating point with the conventional technology.

- The control speed is extraordinarily high at 20 kHz. Thus, even fast-running processes (Plasma, TIG, MIG-MAG, Submerged arc welding) can be controlled in a targeted manner.

- The programming of the Virtual Machine is highly standardized and modularized. The individual defined process states are stored in the form of databases and the values to be set for the current source are linearly interpolated.

- Due to the lack of internal electrical resistances the efficiency is at 95%, while conventional power sources are significantly lower. This also means a significantly lower power consumption.

DC pulse welding

MIG / MAG welding processes have proved their worth for welding unalloyed and low-alloy construction steel. Thanks to the pulsed arc technology, the best process properties for the joining of aluminum alloys and high-quality structural steels could be achieved subsequently.

An important feature of the ELMA-Tech pulsed arc technology is the optimally controlled, regular material transfer, which is controlled by the process control *Virtual Machine* in all phases ideally according to the process parameters.

General objectives for this type of process are safe and maximum gap bridging, higher welding speeds and, for thermosensitive materials, the lowest possible energy input.

Process phases in pulse welding

- Ignition phase
- Basic current phase with reduced energy input:
  Stabilizing of the arc
  Preheating the workpiece surface
- Main current phase:
  Drop separation by precisely defined current pulse
  Short-circuit prevention
  Avoiding a drop explosion
  No welding spatter

Advantages

- High process speeds
- (especially in automated applications)
- Lowest possible energy input
- Positive influence on arc pressure and penetration behavior
- Improved drop separation
- Increased deposition rate
- Reduced weld pool temperature
- Reduced penetration depth with higher deposition rate
- Excellent gap bridging

VM-regulated parameter

Statics pulse phase
- Open circuit voltage
- Characteristic curves slope

Statics basic phase
- Open circuit voltage
- Characteristic curves slope

Dynamics basic / pulse / basic
- Time function current increase
- Time constant current increase
- Time function current drop
- Time constant current drop

Time parameters
- Pulse time
- Basic time

Statics short circuit phase
- Open circuit voltage
- Characteristic curves slope

Dynamics short circuit phase
- Time function current increase
- Time constant current increase
- Time function current drop
- Time constant current drop

AC pulse welding („cold" welding process COLD ELMARC)

Process peculiarities in AC pulse welding lie on the one hand in the modifiable change of the energy balance in the ratio of wire / weld pool; on the other hand different arc characteristics may occur depending on the polarity.

General objectives for this type of process are safe and maximum gap bridging, higher welding speeds and, for thermosensitive materials, the lowest possible energy input (ideal e.g. for aluminum especially in small material thicknesses under 1 mm).

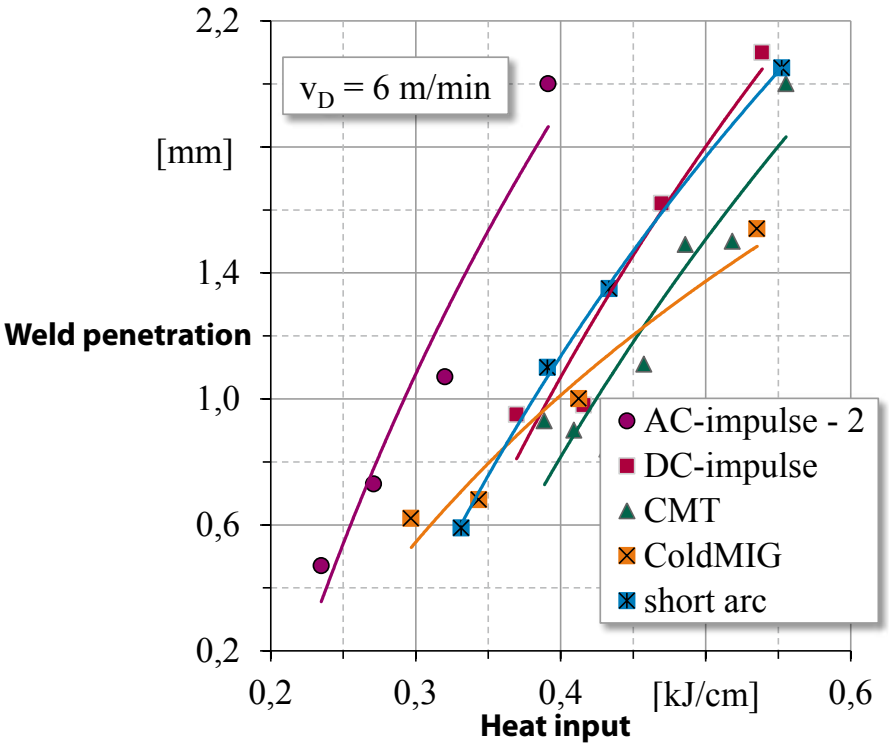
Advantages

- Lowest energy input
- Positive influence on arc pressure and penetration behavior
- Improved drop separation
- Increased melting rate and welding speed
- Reduced weld pool temperature
- Reduced penetration depth with higher deposition rate
- Excellent gap bridging

Aluminum: 1,2 mm
Gap bridging: 4 mm

Lowest heat input in aluminum arc welding

In a study* of the Chemnitz University of Technology, various competitor processes are compared with ELMA-Tech AC pulsed welding.



„With AC-pulse welding, a stable welding process with few splatters is possible when joining aluminum."

„Heat input during welding with AC pulse lower than with CMT"

„Therefore suitable for welding thin aluminum sheets (<1 mm)".

(Quoted from the results of the study)

*
Chemnitz University of Technology, Faculty of Mechanical Engineering, Institute of Machine Tools and Production Process, Chair of Forming and Joining: „Comparison of MSG standard with AC pulse welding for lightweight materials", Author: Dipl.-Ing. Stefan Brumm, 19.06.2015.

Scope of application

Arc wire spraying, plasma coating

For a wide range of ambitious applications in the area of arc wire spraying and plasma coating ELMA-Tech supplies the process control *Virtual Machine* (VM), as well as secondary regulated high-current power sources in the power range up to 3000 A.

Objectives in these fields of application are, depending on the application, e.g. completely individualized injection processes with maximum process reliability (100%), optimized adhesive strength, finest spray textures, high layer thicknesses or also a desired higher layer porosity (the latter for example in the coating of cylinder surfaces in internal combustion engines).

General benefits of using VM process control in arc wire spraying

All optimum spray parameters for a wide variety of spray materials are already pre-set via the expert database. Spray parameter changes are possible during the injection process.

Finer spray coatings with simultaneously lower atomizing gas pressure mean a significant cost reduction. Higher adhesion values are achieved without the use of expensive spray materials.

- Spray- / coating power sources are completely new configurable in terms of statics and dynamics with a cycle speed of 50 µS

  (Statics and dynamics in conventional power sources are in the construction and the coupling of transformer and choke and are therefore unchangeable fixed in the hardware and accordingly inflexible.)

- Totally freely changeable current / voltage curves
- Optional constant voltage or constant current control
- New software-based ignition and spraying processes
- Uniform layer application
- Low thermal load of the substrate

- Adaptability of the segment structure of the process

  A typical segment structure is e.g.:
  ARC START: Arc generation
  IGNITION: Arc takeover
  SPRAYING: Segment of spraying
  END OF SPRAYING: Drop separation, burn-off

- Stable, constant arc guaranteed even at a power of only 10 amps

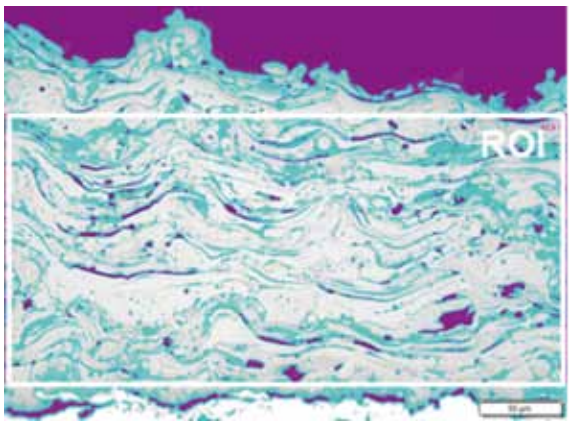
Arc wire spraying (AWS) with pulsed direct current (DC pulse)

Compared with other thermal spray processes, the inhomogeneity and porosity of the produced layer is usually higher when using AWS. As already mentioned, layer porosity is very desirable in some applications. A requirement to be met thereby lies in the requirement, that the pores are uniformly distributed throughout the complete cross section. Non evenly formed layers however are to be avoided!

The cause of non-uniform layer properties originates from the stochastic melting process of the wire electrodes in the arc. Due to different arc shapings at the anode and cathode, the wires are melted unbalanced. In addition, the arc length is not constant with conventional AWS power sources.

The use of AWS with DC pulse under a process control with *Virtual Machine* offers the following advantages:

- Increase in the melting rate / application rate
- Reduction of the heat load of the substrate by lowering the process temperature
- Production of homogeneous and pore-minimized layers
- Targeted and controlled particle separation
- Lower process emissions



First results * of corresponding scientific accompanying research meanwhile prove the very good process results when using the DC pulse process also in the arc wire spraying:

„By varying the spray parameters in the pulsed LDS process with a prototype system and the spray gun from OSU-Hessler, a stable process characteristic and improved coating results could be demonstrated compared to conventional AWS."

* Abstract „Arc wire spraying with pulsed direct current" (authors: D. Landgrebe, S. Brumm, S. Kunze, S. Weis) TU Chemnitz, Institute for Machine Tools and Production Processes; Westsächsische Hochschule Zwickau, Institute for Production Technology, Professorship for Joining and Coating Technology. 2018. (not yet published). The work carried out is currently funded by the BMWi as part of a ZIM cooperation project.

Conclusion

The process control *Virtual Machine* (VM) can be considered as the essential technological core of the welding and coating technology of ELMA-Tech. The VM is used as welding and spraying process control in the by now third generation exclusively by ELMA-Tech worldwide and establishes the technological top-level that ELMA-Tech takes nowadays.

Currently, over 5,000 VM applications are found worldwide in the automotive and other industrial sectors, such as steel pipe construction and mechanical engineering.

The unique control concept of the VM optimizes, through process segmentation in combination with innovative power sources, the management of different processes in the fields of application described above on an absolutely high quality level.

Legal notice

The process control *Virtual Machine* is based on in the patent DE 32 00 086 C3 (05.01.1982, Puschner, P.) exposed and still valid technology for synthesizing static and dynamic behavior of electronic generators for welding applications and realizes the technical teaching described therein in a unique way.

With the advancing development of microprocessor technology, the *Virtual Machine*, already created in the structure in 1992 under the working title „Konzept 2000", could be implemented for the first time in 1997 with a cycle frequency of 2 kHz - and only a few years later with 20 kHz.

The process control *Virtual Machine* and the process programs running in it are subject to copyright worldwide with the resulting legal protection. The only licensor is ELMA-IVG mbH in Aachen, Germany.

Currently, the Virtual Machine in its hardware, its basic program and the process programs required for the various processes, is developed and distributed worldwide exclusively by ELMA-Tech GmbH in Morsbach, Germany, and its cooperation partner Lachmann & Rink GmbH, Freudenberg, Germany ,

Company

In the field of plasma-arc and resistance technology ELMA-Tech GmbH achieves with their "made in Germany" welding machines and its microprocessor-based control *Virtual Machine* particularly unrivaled results at the customer in terms of welding quality, process safety and energy efficiency.

This automatic multi-function welding process control allows in particular fully automatic resistance spot welding without any parameter presettings.
The specific research and development in resistance welding with the use of unique virtual technologies in the field of measurement and generator technology allows both the safe welding of most actual high-strength steels and thin aluminum sheets, which are used more and more in automobile production.

All ELMA-Tech spot welding systems are equipped with fully automatic hand- or robot-guided spot welding guns in X, C and innovative V-arrangement, developed and designed for the production lines of automotive plants and for the industrial sector.

The performance profile also includes self-made high-tech welding power sources for arc welding and coating technology (arc wire spraying). The portfolio is supplemented by accessories such as vehicle repair guns, spotter and various other system components.

Customers of ELMA-Tech GmbH come from the field of industry and automotive (automobile manufacturers, suppliers, vehicle and body construction), as well as from the field of car workshops.

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