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Advanced Super-Finish Wire-EDM and Coating Technologies for Improved Tool Production

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Abstract

Long production times for the main cut and poor coatability of the processed surfaces constitute serious disadvantages of the Wire-EDM technology. The wire-cut surfaces require time-consuming manual post-processing prior to coating. This manual finishing reduces the accuracy-to-shape of the tools. Within a research project carried out by an international consortium of well-experienced partners out of different technological areas, it was aimed to improve Wire-EDM and Coating technologies in terms of efficiency and coatability. On competition of the project, an advanced super-finish Wire-EDM and coating technology for improved pressing and punching tool production has been realized, enabling Wire-EDM super-' finished tools to be directly coated without the necessity of any mechanical pretreatment. Moreover, two new machine prototypes incorporating a generator for high-speed and super-finish machining, an expert process control and features like automatic wire threading and a multi-wire system have been developed. In addition, the appropriate wire electrodes for high-speed and super-finish machining are available.

Introduction

The introduction of continuous Wire-EDM to industrial practice in 1969 revolutionised the manufacture of punching, pressing and extrusion tools, and rapidly led to its achieving a monopoly. The process has also gained acceptance in prototype production and in series production e.g. for the aerospace industry.

In the Wire-EDM process, the material is removed by means of temporally and spatially discrete discharges which produce local vaporization and melting in association with ejection processes. This enables all electrically-conductive materials to be processed without significant exertion of force, irrespective of their hardness.

Continuous Wire-EDM cutting comprises two successive processing steps. A main cut (high discharge energy) is carried out first, in order to cut out the desired geometry from the solid material as rapidly as possible, with an allowance for the secondary cuts. Accuracy and surface quality are still unsatisfactory after the main cut. The discharge energy is then gradually reduced during a series of 1-7 secondary cuts, to obtain high accuracy and good surfaces quality.

In past years, numerous innovations and improvements in the continuous Wire-EDM sector have contributed to a distinct improvement in the cost-effectiveness of the process. Examples are devices for automatic wire threading following wire breaks or following internal machining steps, higher-performance control systems and generators which allow higher cutting rates.

Despite these developments in Wire-EDM, certain weaknesses still severely detract from the usefulness of the process. Long production times for the main cut and poor coatability of the processes surfaces constitute serious disadvantages of this technology. The wire-cut surfaces require time-consuming manual post-processing prior to coating. This manual finishing reduces the accuracy-to-shape of the tools.

Within a research project which acronym is WECAT, it was aimed to improve Wire-EDM and Coating technologies in relation to the above mentioned weaknesses. The overall objective of this project was the development of a comprehensive technology for high-quality time- and cost-saving production of coated punching, pressing and extrusion tools made of carbides, high-speed steel and high-alloyed steels. This requires highly-developed wire-EDM machines with improved technology capable of high-speed and super-finish processing, together with two new wire electrodes specially updated for these applications. In addition, the associated coating technology requires further development to achieve first-time TiN coating of super-finished wire-EDM surfaces without time- and cost-intensive manual finishing. Tool life tests on coated punching tools should accompany development of the coating technology and document the improvements achieved.

In order to succeed in this project, an international consortium was founded covering all the involved research areas needed for the developments. In detail, this consortium consisted of a manufacturer of EDM machine tools (ONA), a manufacturer of NC controls (MIKROA), a producer of wires and wire electrodes (Berkenhoff), a research institute for manufacturing technologies (WZL) and a manufacturer and developer in the field of coating technologies (Hauzer). Each partner represents an expert in his field

The overall project objective was divided into the following sub-objectives:

increased cutting rate in the main cut (high-speed machining),
reduced surface roughness and surface zone influences in the secondary cut (super-finish machining) and
improved adhesion of the TiN coating to the wire-cut surfaces.

Technical description

The researches and developments carried out within the project have been divided into the following areas:

a) high-speed machining
b) super-finish machining
c) expert process control
d) new production Wire-EDM machine
e) coating technologies including the final application of coated punching tools.

a) The achievement of increased cutting rates in the maincut required different developments, such as a new high-speed generator and its adaptation to the machine, a special wire electrode and the necessary EDM technology.

The developed high-performance generator incorporates modern MOSFET components, in order to allow short-duration of pulses which will increase the cutting rate. This generator has been integrated with the Numerical Control (CNC), establishing the adecuate interface to get a regular process control. Through the development of a servo gap control and a real time expert system, thus, it becomes possible to reach high efficiency of the process avoiding stop periods.

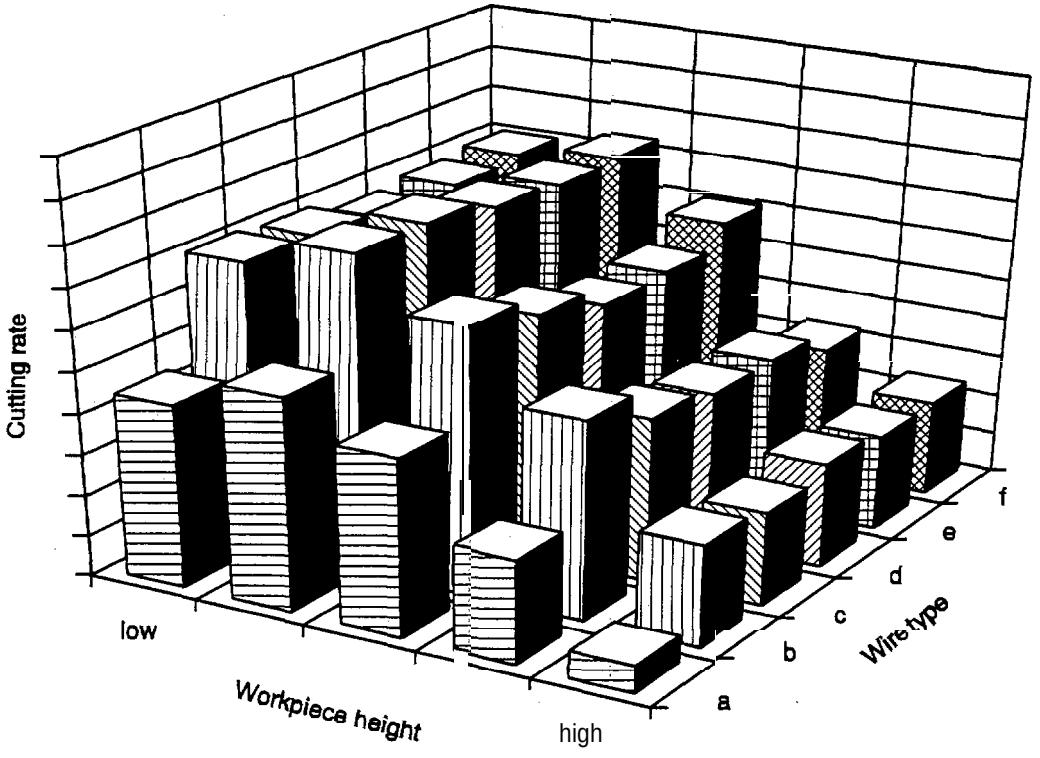
The wire electrode was aimed to achieve maximum cutting speed in combination with the high speed generator, the flushing system and the software working together. The electrode had to be adapted in order to meet the requirements of the wire guiding system and the automatic threading system. During the test series the impacts of the principle influencing factors have been analyzed and assessed in detail.

The mechanical strength of the electrode has an important influence on the geometric accuracy of machining. A high pre-stress force can compensate the affects of the process specific force effects on the wire electrode and hence damp vibrations. The appearing bulging and oscillation amplitude can be reduced accordingly.

The second important property is the thermal and electric conductivity of the electrode material. The electrode has to transport the entire electric energy of the pulse from the current contact to the spark spot. A high electric conductivity causes less transmission losses by the ohmic resistance and consequently a lower heating of the electrode. Furthermore in materials with high thermal conductivity the heat is rapidly dissipated from the spark-over spot to the basic material. Either prevent a detrimental overheating of the wire and consequently the risk of a wire break can be minimized.

The major effect is attributed to the chemical composition, especially the zinc content of the electrode. Zinc has a very low melting and evaporation temperature. Hence a formation of a plasma channel is supported and higher pulse frequencies are possible.

Within numerous and extensive test series, the influence of the generator, the wire electrode and the machining parameters on the cutting rate has been investigated. Based on fundamental studies, the best performing wire electrode and optimized machining conditions were established in special test series. An example for a result of a cutting test investigating different wire types and workpiece heights is depicted in figure 1.



Workpiece material: X 210 Cr W 12

Figure 1: Results of a high-speed machining test with different wire types and workpiece heights

b) In the field of super-finish machining it was likewise necessary to develop a new generator, a high-accuracy smooth-operation NC feed systems, a wire electrode and the suitable EDM technology allowing for producing smooth and coatable workpiece surfaces. A main characteristic of EDM is the formation of the so called white layer i.e. the surface layer of molten and resolidified material which cannot be avoided completely in EDM. In order to ensure a good coatability the white surface zone must be as thin as possible, homogeneous, crack -free and well-bonded to the substrate material.

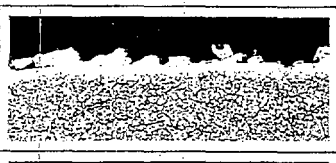
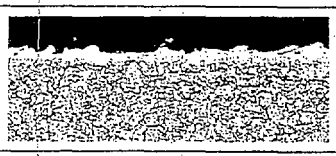
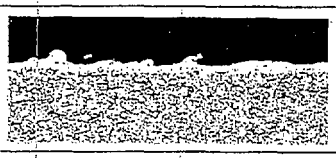
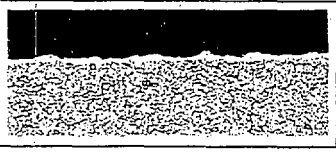
The super-finish generator has been designed to achieve discharge currents significantly below 1 A and discharge frequencies of up to 4 MHz. Minimization of all capacitances in the circuit was required in order to prevent discharges of an energy several times the value of a normal discharge (capacitor effect). These actions were necessary partly in order to achieve the desired low surface roughnesses and partly in order to ensure the coatability of the white surface zone. The super-finish generator and the high-speed generator have been integrated to one unit.

Also the wire electrode for super-finish machining has to fulfill the requirement of processing a workpiece in such a way that subsequent coating with PVD is possible without a mechanical post-processing. Besides the requirements for electrodes described in general under "high-speed machining.", it is of particular importance at finish cutting to minimize the material residues on the cut surface,

The tests showed that the element zinc is again an important factor. The higher the zinc percentage of the alloy, the fewer the residues of the elements copper and zinc on the workpiece surface.

As the removal rate is considerably smaller at finish cutting than at speed cutting, the zinc coated wires proved to be the best ones. Due to the special treatment of the surface of the coating it was possible to produce finest surfaces with only insignificant residues of the wire material and with the white layer being almost completely avoided.

The influence of the wire electrode and the machining parameters on the resulting workpiece surface was determined in fundamental studies as well as in subsequent test series optimizing the machining conditions. The investigations mainly focused on the minimization of surface roughness and the thickness of the white layer. Figure 2 shows a typical result of a super-finish machining test with the new generator and a zinc coated wire electrode.

Machining step	R_a [µm]	R_z [µm]	Thickness of white layer [µm]	Microsection [⊢—⊣ 20 µm]	SE image of surface [⊢—⊣ 20 µm]
Maincut	3,17	18,60	10		
1. trimcut	1,21	7,27	6		
2. trimcut	0,95	6,21	4		
3. trimcut	0,34	2,41	2		

Workpiece: ASP 23, 59 HRC; Wire: WECAT No. Z3, d = 0,25 mm

Figure 2: Surface roughness and topography after the maincut and the first three trimcuts

c) The Expert process Control refers to the autonomous work of the machine enabling to operate with maximum cutting rate i. e. at the performance limit of the wire, avoiding wire breaks. In order to achieve this goal, different facilities of the machine such as wire feed and guidance system and dielectric supply have to be coordinated. But the most important factor is the quick evaluation of process status to take preventive or corrective actions in order to optimize the process. The maximum effectiveness of the cutting process is achieved by avoiding wire breaks because of the lost of time in recovering from wire break, and afterwards, once more optimizing the cutting process. Different operation strategies and a wire break prevention strategy needed to be developed. Hardware adaptation and Software development represented further tasks in this area.

d) In the field of the mechanical aspects of a machine prototype, it has been performed the design and development of a system which represents a complete wire electrodischarge machine, incorporating capabilities as follows:

- Possibility of supplying wire for the electromachining process from an incorporated spool of any size (from the small DIN100 up to the 45 Kg wire weight DIN3 55), the latter allowing for a long period of uninterrupted work in workpiece cutting.

- Effective absence of the vibrations coming from the uncoiling of the wire in the spool or originated during its transport, due to the inclusion of a system placed before the machining zone that eliminates completely any possibility of knock or vibration transmission.

- Also this system allows wire feed from the spool without the adding of extra-effort to the main wire feed roller of the machine. The added wire mechanical tension to uncoil the spool, independently of its size or weight, is practically not existing.

- The design of the system allows taper cutting up to 30° in workpieces, a characteristic that is complemented with the development of a version of the prototype with submerged flushing.

- This submerged flushing allows the cutting of high angles in taper cutting, machining without difficulties in complex shapes and sections, and an improvement of the super-finishing characteristics of the prototype,

- The prototype incorporates an automatic threading system for the wire, that performes the fully automatic work of it, having the option to work for long periods, i.e. several days, without the assistance of the operator, This system is in charge of doing the operations that the wire electrodischarge machining implies for the operator: once finished a job, to change to a new one and execute it or to solve and restart the job after an accidental wire breakage.

- A possibility of the system is the incorporation of two different specialized wires to carry out a job automatically. One of the wires is designed and applied for the maincut at high speed. The second wire is also specially used but for the super-finishing of the surfaces. By using this automatic system, the machine is in the position, first, to carry out the whole job, from the beginning until the end, in an unattended manner, using the most specialized wires for each operation, and secondly to achieve a minimum machining time.

  The system, in both machine versions -submerged or not- incorporates a fully automatic filter which has neither maintenance, nor spares, and that produces the less possible residues: only dry sludge from the electrodischarge machining process, ready for an easy manipulation before its further recycling.

e) In order to get a cost effective production of high accuracy TiN coated punching, pressing and extrusion tools, it will be a big improvement if there is a direct TiN deposition on wire-EDM surfaces. There would be a cost saving of roughly 20°/0 of the overall toolmaking costs, because of the elimination of post-processing (between wire-EDM and TiN coating). Up to the start of this project it was not possible to get rid of mechanical pretreatment steps like grinding and polishing before TiN coating with the known PVD techniques (for example low voltage electron beam, arc or sputtering).

The reason for the failure of TiN coatings deposited with the mentioned techniques, is the existence of the white layer. Transmission electron microscopy was used to analyze the outer surface zone. This investigation yielded that the analyzed area consists mainly of an extremely fine martensitic structure with local amorphous zones. It seemed to be necessary to modify or even get rid of this white layer before starting the deposition of a ceramic layer (TiN and TiAlN within this project). If this can be done in the right way, it will be possible to transfer the specific coating properties towards the wire-EDM machined tools, without failure at the interface.

Thus, a modified PVD coating technology had to be developed, producing a good interface between the substrate material and the TiN film to permit high coating-substrate adhesion, The PVD coating technologies unbalanced magnetron sputtering and arc ion-plating were combined, and the arc etching step in particular was designed to remove the minimized white layer still remaining on the workpiece surface and/or to modify its structure in such a way as to eliminate brittleness in the surface zone.

Numerous laboratory tests with reference to coating adhesion were carried out to optimize the special PVD coating technology. The final step has then been the industrial testing of coated fine blanking tools (piercing punches) in order to prove the coating adhesion under real conditions. Within this step, investigations focused on the development of tool wear and surface quality of the blanked parts which indicates the quality of coating adhesion (figure 3).

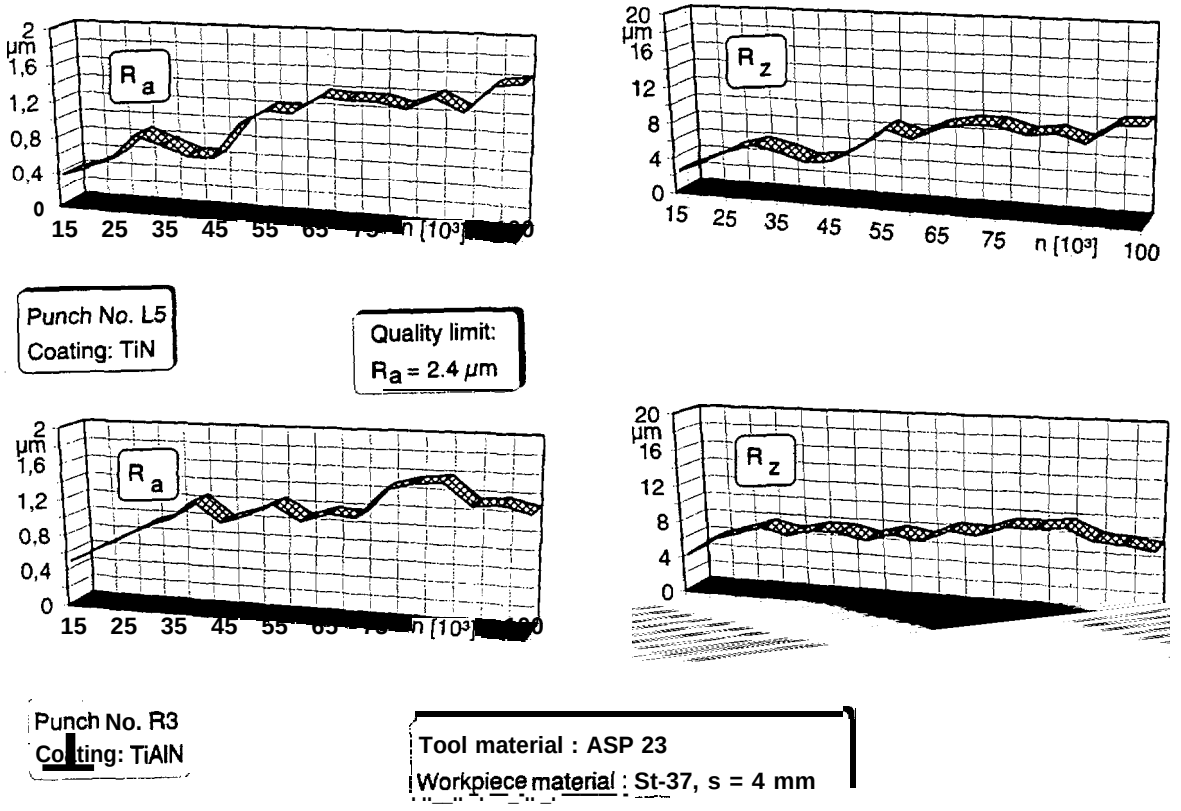


Figure 3: Surface roughness of blanked parts

Results

As main result of the project, the overall objective - development of an advanced super-finish Wire-EDM and coating technology for improved pressing and punching tool production- has been achieved. Within the final industrial application of wire cut and PVD coated fine blanking punches, a tool life improvement at least by factor 6 as compared to uncoated punches could be attained. This outstanding result became possible through the improvements made in the different development areas involved in this project. Furthermore, it proves that it has been realized to deposit ceramic layers of excellent coating adhesion on Wire-EDM super-finished surfaces without any mechanical pretreatment.

The results achieved in the different development areas according to the before made division can be stated as follows:

High-speed machining:

As a consequence of the development of a new high-speed generator, the appropriate wire electrode and the adapted technology based upon the conducted fundamental studies, the cutting rate in the main cut using wire electrodes with a diameter of 0,25 mm could be increased up to 380% with regard to the initial value in the project with.

In relation to the development of wire electrodes, the tested factors showed that the zinc content of the electrode presents the most important influence. As wires with a pure zinc coating caused too high wear and abrasion of the zinc coating, electrodes with brass surface, containing 50 % zinc, were developed. The embedding of the zinc into the brass matrix avoids a rapid abrasion of the coating rich in zinc. So there is a sufficient amount of zinc also for high workplaces. The sufaces of the wire electrodes being abrased just as much as the workpieces, the thickness of the coating was adjusted to the actual requirements, This ensures that the coating is not abrased completely. The test with different chemical compositions of the electrodes showed that this extraordinary feature in the wire erosion process can only attributed to zinc. No other material combination showed similar good results.

The electric conductivity seems to be of minor importance for this type of generator. The improvement of the cutting rates with high conductive electrodes compared to mean conductivity was considerably smaller than expected

A tensile strength of the wire electrodes of 800-1000 N/mm² is sufficient for the tensile load. A further increase did no prove to be necessary,

An increase of the cutting rate may also be achieved by enlarging the diameter of the used electrode. The cutting rate increased by 30 % with an enlarged diameter from 0,25 mm to 0,30 mm. A further enlargement of the diameter to 0,33 mm and 0,35 mm is possible, However, the limitation of the diameter depends on the workpiece to be processed, especially the size of the internal radii.

Super-finish machining:

The progress in this area is likewise based upon fundamental studies. With the new developed super-finish generator, a zinc-coated brass electrode and the adapted technology workpiece surface roughness can be reduced down to a value significant y less than R_a = 0,5 pm. Hauzer and WZL experienced that a roughness of R_a = 0,5 μm is sufficient for an adequate coating process and most of the applications. With respect to the state-of-

the-art, a big step has been made towards the top area of super-finish machining. Moreover, the above mentioned result is obtained in only three trimcuts, hence a contribution to further efficiency of the Wire-EDM process. Therefore, this result can begarded as a great improvement. Some typical wire electrodes, tested within this project, are depicted in figure 4.

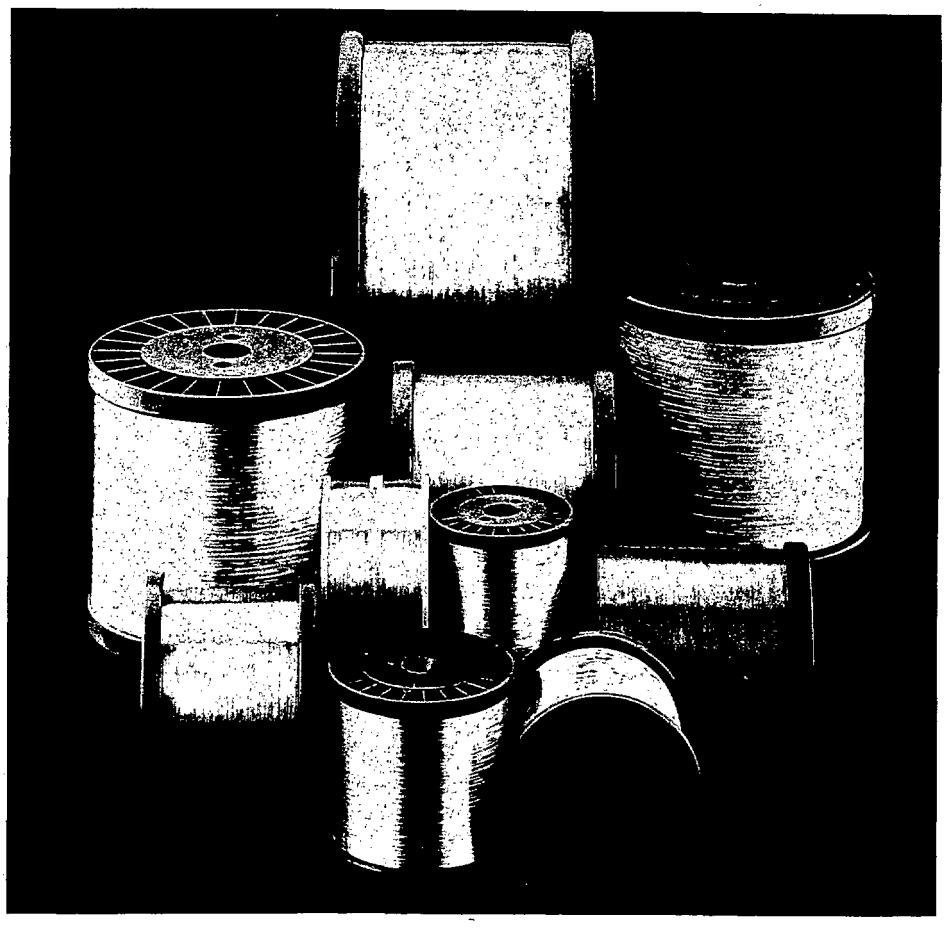


Figure 4: Some typical wire electrodes

CNC and Real-time expert system:

A real-time expert system for sharp corners and small radii has been developed and implemented to avoid wire break and to increase the accuracy of cut parts.
A Fuzzy Logic Inference Motor Controller has been designed and developed as the basic support of the application level for Expert Process Optimization.
The actualization of the CNC includes:

- Design and development of a Master Board CPU 68000 (16MHz) to get greater processing capacity for VME bus.
- Design and development of a Motor Control Board, controlling up to 4 motors, 68000 based (16MHz), carrying out the position, velocity and Servo Gap Control System. The position accuracy has been increased by means of linear scales.
- Integration of the VID 30 Video Graphic Cotroller board to meet the requirement of access and managing graphic information to operator.
- An interactive machine operator software periphery has been implemented. Programming and operating the CNC are made through a friendly User Interface which has been developed. Two planes graphic representations of the shape to be cut, in Edit, Simulation and in Real Execution time are implemented(figure 5).

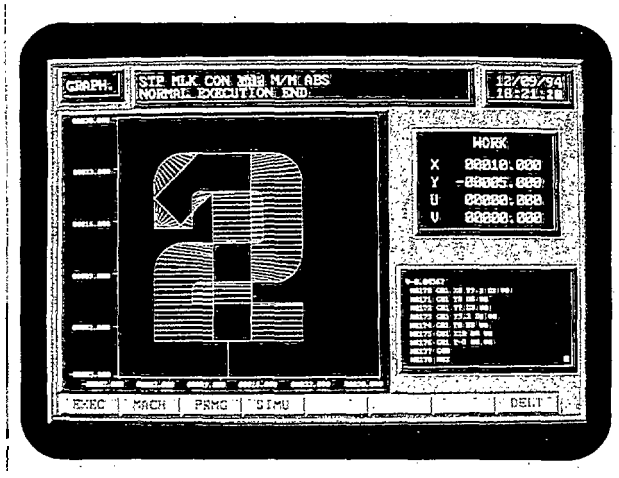


Figure 5: User Interface

The following features, among others, have been developed:

- Piece contact
- Centering cycles
- Inner centering
- Outer centering
- Selection of generator parameters by the pair wire/piece and by individual settings
- Technological tables
- Servo gap control system
- Automatic sequences (PC) to control the generator
- Auto-wire threading management system (AWT)
- Automatic wire rethreading
- Jump function
- Automatic vertical position finding
- Automatic setting condition for start cutting.

A wire break prevention strategy (patent pending), based on experimental studies of wire breakages has been developed and realized by hard- and software development for integration into the Real-time expert system; The following results have been achieved:

- On-line measurement of discharge location
- Decrease in wire break risk
- Avoidance of wire breakage and increase in cutting rate for particular machining cases
- Possibility of workpiece thickness measurement during the machining.

Wire-EDM machine tool:

On completion of the research project, two machine prototypes have been realized, one using water flushing in air, and a posterior second one using submerged flushing, both automatic and comprising the characteristics explained in the technical description. The first one, conveniently industrialized, is already in the market (figure 6) , and the second one is planned to be launched soon to it.

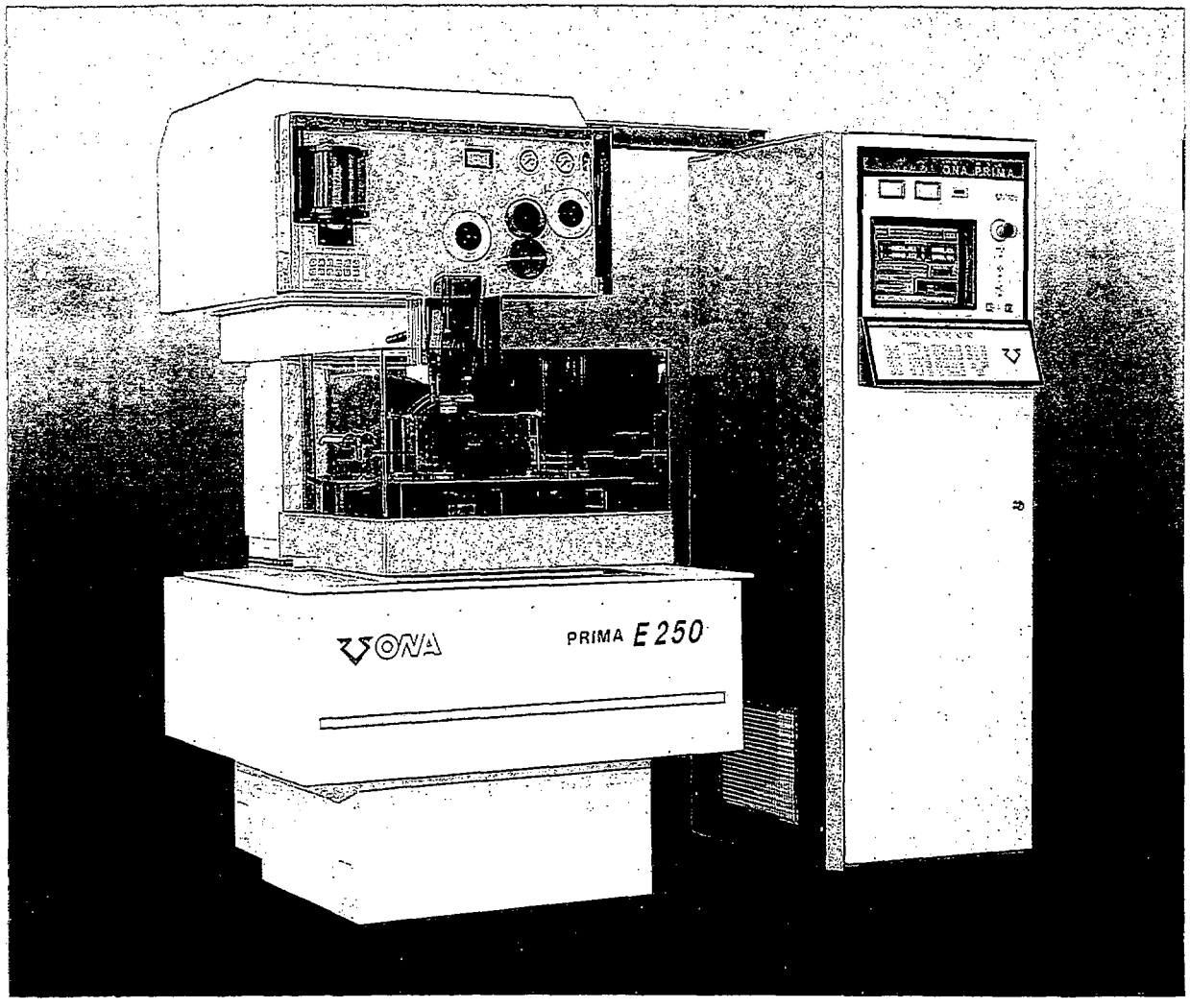


Figure 6: Wire-EDM machine tool

Coating technologies:

A modified Physical Vapour Deposition (PVD) coating technology has been developed producing a good interface between the substrate material and the coating itself to ensure high coating-substrate adhesion. The PVD coating technologies "unbalanced magnetron sputtering" and "arc ion-plating" were combined. This new technology is the so called "Arc Bond Sputtering (ABS) technology". The ABS coating technology is continuously in development. The ABS coating technology can fulfil requirements from the market and is at this moment on an industrial production standard (figure 7).

Industrial W-EDM punching tools have been coated according to the knowledge gained during this BRITE-EURAM project. This coating was done without mechanical pre-treatment. The coated tools were tested in a fine blanking process, investigating the

development of tool wear and workpiece quality. All applied punches worked properly and in comparison to uncoated punches, an improvement in tool life quantity at least by factor 6 was attained. This result emphasizes the excellent coating adhesion on the wire cut punches.

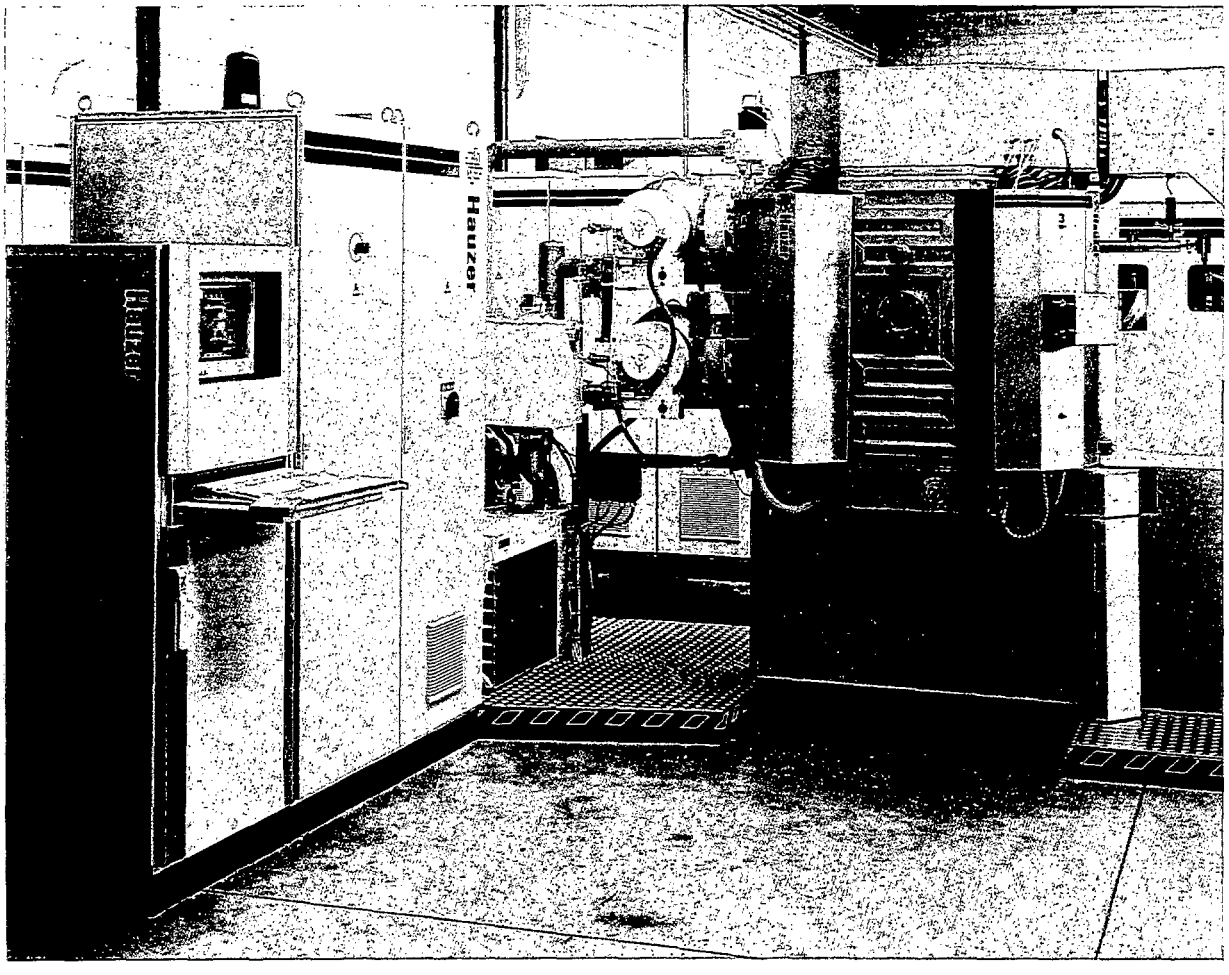


Figure 7: Example for a PVD coating equipment

Conclusions

Within the WECAT project, an advanced super-finish Wire-EDM and coating technology for improved pressing and punching tool production has been realized. Through these developments Wire-EDM super-finished tools can directly be coated without the necessity of any mechanical pretreatment. A final industrial application of coated fine blanking tools has proved this. This means a great advance for both, Wire-EDM and PVD coating since its efficiency for the application of tool making has increased. The results of the WECAT project might encourage a lot of companies, working in the field of pressing and punching tool making or users of these tools, for a more intensive use of the PVD coating technology in order to produce high-quality tools in terms of performance and tool life. The new, so called Arc Bond Sputtering (ABS) technology which can fulfill requirements from the market is at the moment on an industrial production standard and continuously in development.

The development of two new machine prototypes incorporating a generator for high-speed and super-finish machining, an expert process control and features like automatic wire threading and a multi-wire system can be regarded as a big increase in efficiency of Wire-EDM.

The requirements for the wire electrode depending on the specific application could also be determined within the project so that it is possible to choose the optimal wire electrode for each operation.

Moreover, the WECAT project may be evaluated as really positive for another reason: all involved partners are able to benefit from the project since they could advance widely and deeply in their technologies. In particular, the machine manufacturer ONA is now planning further developments to be launched to the market in short or medium term, which have their origin in the studies of the Project.

Finally, the interaction between the partners has given to them a better knowledge of Wire EDM complementary technologies, like wire composition and production methods, theoretical studying methods and workpiece surface coating necessities, enabling a better understanding of market needs and more ways to solve them.

Acknowledgements

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