CHARMILLES TECHNOLOGIES: FACING THE FUTURE

by

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0. INTRODUCTION

Charmilles Technologies, a George Fischer company, acquired his new headquarters in Meyrin Geneva in 1988 and is one of the world leading EDM Machine Tool Builders since 1954. Its activities are spread out over the globe and are assured by its divisions in Japan, U.S.A, France, W. Germany, the United Kingdom, Italy and local representatives. The company is striving towards the future through an increasing performance of its products and customer services.

To face the Japanese and Asian markets, Charmilles Technologies LTD Japan was founded in 1988, and new facilities have been erected recently to serve better our Japanese customers. On behalf of Charmilles Technologies, it is a real honor to address You research partners, today at this CTSA - EDM Research Conference. I will present You an overview of the EDM business activities, from where we came, where we are, and where we shall go to in the near and far future.

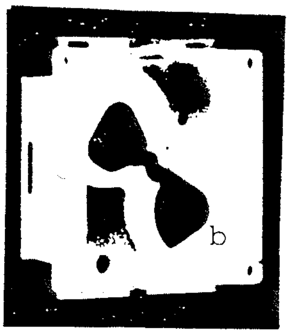
The structure of the Research & Development Division, its activities and situation will be highlighted as well. In addition, some generalities of the Applied Research Department as well as its links with worldwide research centers and laboratories will be discussed.

1. SHORT HISTORICAL OVERVIEW OF THE EDM EVOLUTION

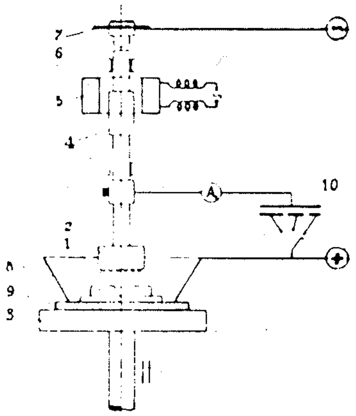
As in many other technical field, the application of electrical discharges for production means had to wait until a request rose out of production problems. The phenomena of electric discharges over a gap have been described already in 1694 by Boyle 1751/1766. Benjamin Franklin and Joseph Priestly observed the metal removal by electrical discharges. Meritens (1881) started to apply arcs for welding applications, and Kohlschütter used discharges to produce colloidal metal powders in 1900. A first know-how about discharge applications was reported.

During the thirties, several patents were granted for the so called "arc disintegrators".

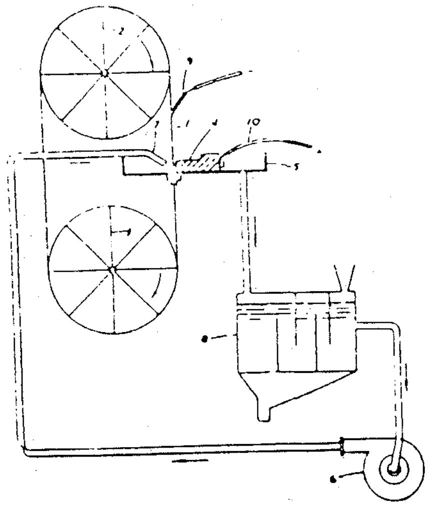
During world-war two, a further substantial push evolved from the investigations of wear causes of electric power contacts. The Russian couple Dr. and Mrs. Lazarenko realized that arcs, in stead of wearing electric switching devices could also be applied for nice machining. Active EDM research took off in the fifties; EDM equipment came on sale in the early fifties by the Russians, the Americans, the Europeans (Switzerland and the U.K.) and the Japanese.



COMPLEX GEOMETRY
REQUEST



LAZARENKO, B.R.
GB-Pat 637 793
Priority : Sept 24, 1946
"A method of working metals'



RUDORFF
GB-Pat 637 872
Priority : Apr 10, 1947
"Apparatus for cuttin electrically"

First W-EDM machine in 70.

Figure 1. *Starting of the EDM development.*

Figure 1 shows the first basic patents granted for EDM die sinking (Lazarenko) and wire cutting machining (Rudorff), as well as the influence of the workpiece characteristics (hardness) on the EDM applications.

Today one can recognize some 15 major EDM manufacturers, among more than 35 brands. In the past, the yearly market growth rate of EDM units was of the order of 25%. Currently, the consolidated production rate of all EDM manufacturers together (worldwide) is of the order of 10'000 units a year. For more information on this matter, please refer to ref. [1].

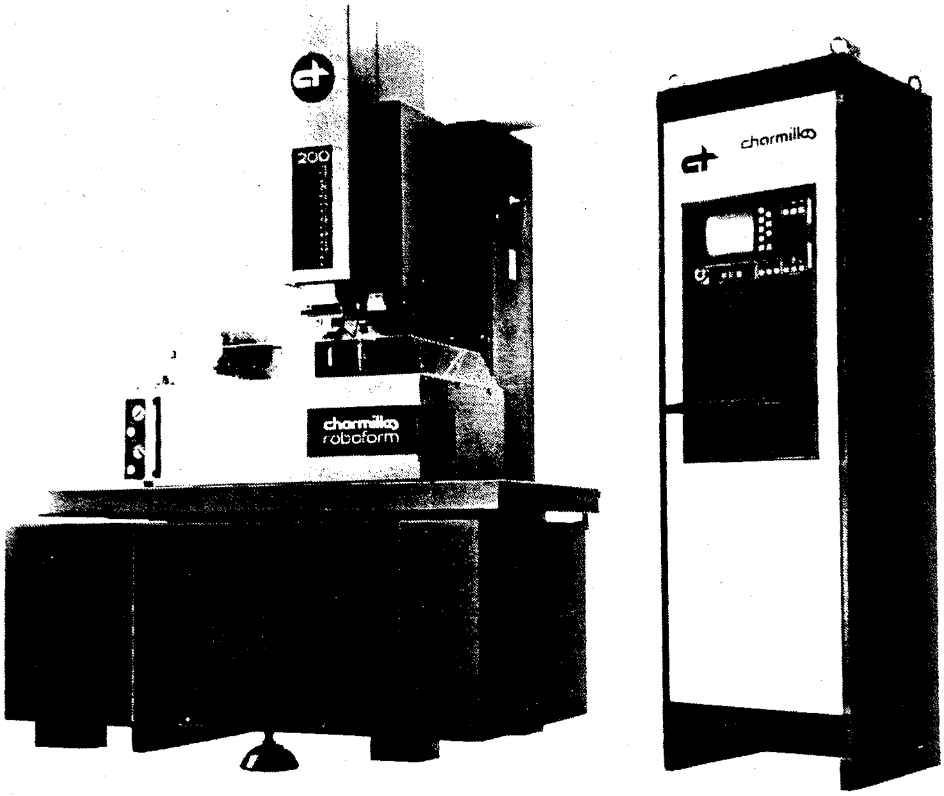


Figure 2a. *The Roboform EDM die sinker.*

Since the introduction of commercially available EDM systems, more than thirty years ago, a remarkable increase of machining performance can be noticed especially in the last two decades.
Although classical machining methods are still more attractive where stock removal rate is the primary concern, EDM has its niche. Spark erosion is often applied in die making but its application area is widening very rapidly these days, due to the very advanced EDM equipment available on the market today. The permanent evolution of spark erosion machines can be emphasized by the following key points.

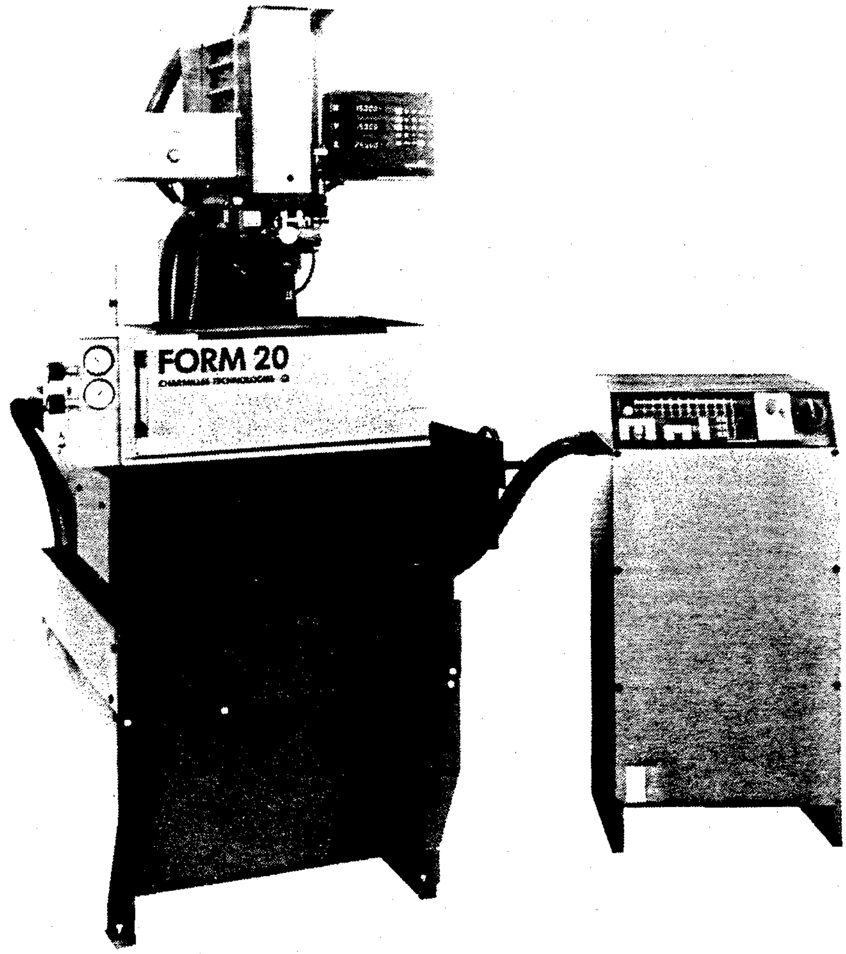


Figure 2b.   *The Form 20 "low cost" die sinker.*

a) Die sinking machines, Figure 2a and Figure 2b.

- Orbital movement of the tool electrode, enables producing very complicated 3D workpiece shapes with a rather simple tool electrode.

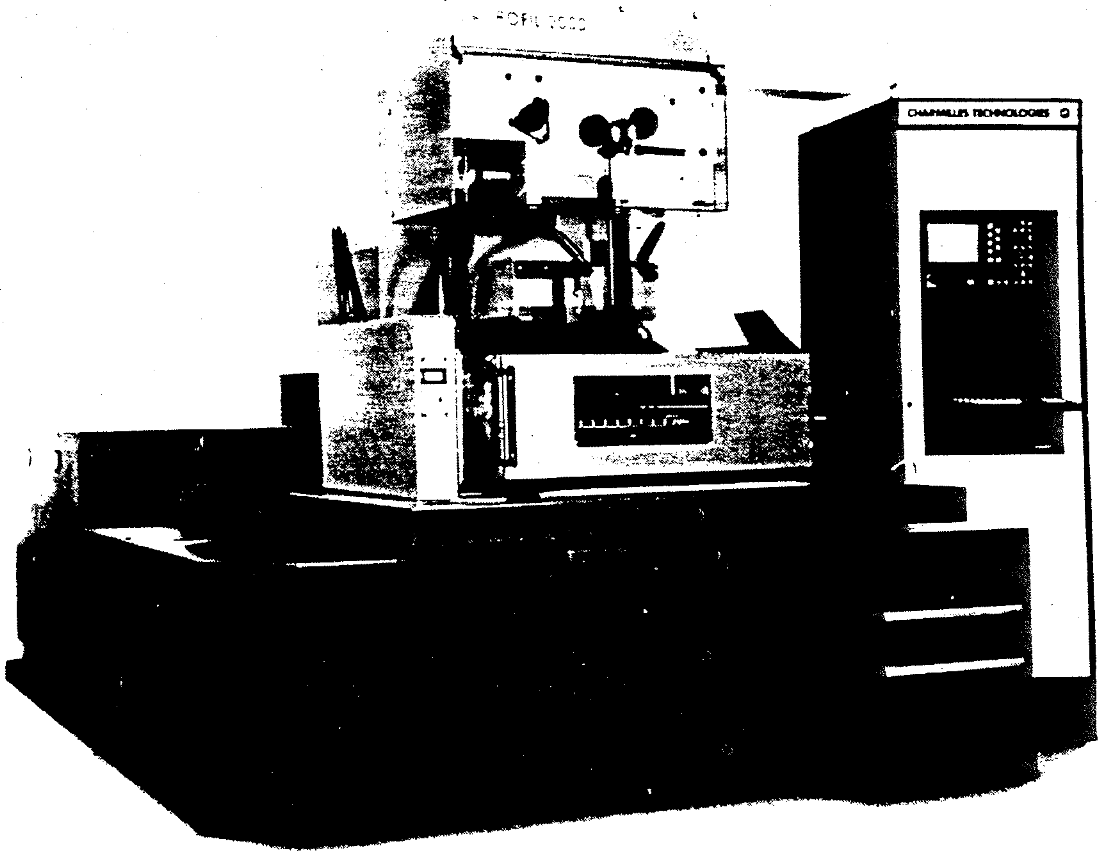
- Improvement of machining performance by advanced generator development.

- Substantial higher cutting rates combined with extreme small tool wear.

- The introduction of "mirror polishing" allows for workpieces to be machined and finished automatically with surface polishing included. Very smooth surfaces can be obtained which means that EDM becomes compatible with other techniques as honing, lapping, finishing grinding, etc.

- Numerical Control (NC) facilities allow accurate table and tool positioning (order of μm) for precise workpiece machining with accuracies up to a few μm.

- The integration of EDM units in the factory is also readily available. Die sinkers and wire cutters are designed to make the "CIM" concept, "Computer Integrated Manufacturing" realizable, par. 5



<u>Figure 3.</u> *The New "Intelligent" Robofil 2000 EDM wire cutting machining center.*

- The improvement of machining autonomy through the concept of automatization. The integration of machining strategies, including various EDM technologies for the machining of many sorts of materials has been made available in the CT EDM units, par. 5.

b) Wire cutting machines, <u>Figure 3.</u>

- The application of specially treated wire as tool electrode yielding a cutting speed substantially higher than when standard wires are applied.

- Introduction of multi-axis control increases the degrees of freedom of the wire guides. It creates the possibility to machine ruled and sculptured surfaces. E.g., turbine blades.

- A constant upgrading of the wire cutting speed. Cutting speeds have been increased by more then 250 % during 1969- 1985. This alongside with better accuracy of the final workpiece.

- Long term machining capability for long jobs (70-100 hr). Some other important facts that EDM is still in progress reveals from the evolution of the American and Japanese markets, [3].

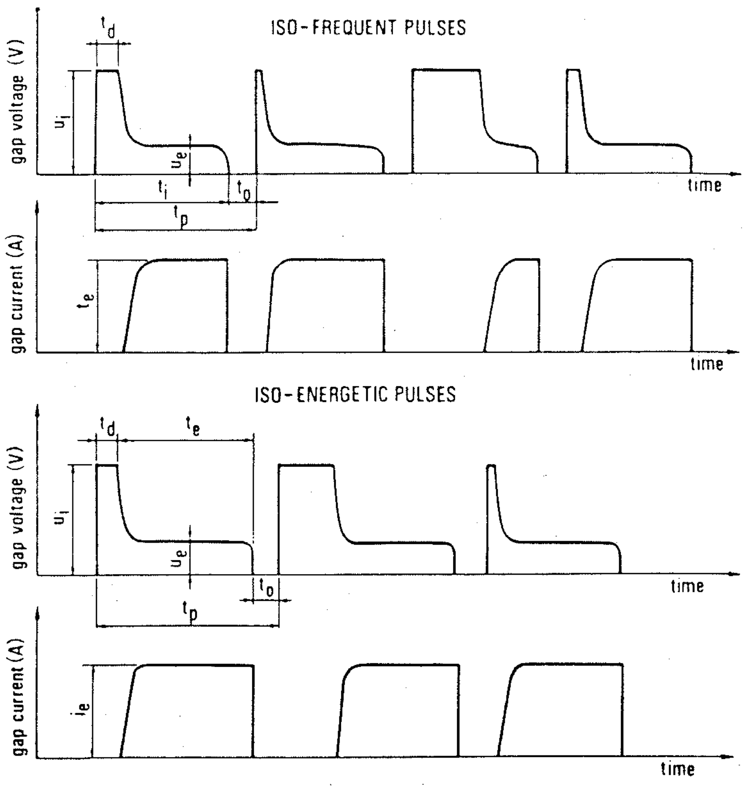


Figure 4. *Iso-frequent and iso-energetic discharges.*

Important to notice is the development of the so called "**iso-pulse**" generators, _Figure 4_, and see also par. 2.2.1. The iso-pulse generators, also called iso-energetic generators are built, such that the specific discharge energy, i.e. the energy contents of a discharge occurring in the gap remains constant, for a preselected generator regime. This is made clear in *Figure 4*. As one can recognize on the figure, iso-frequent generators do not always generate pulses of constant energy. Consequently, it implies that each specific crater volume to be removed (i.e. the amount of material to be removed per pulse at the workpiece) cannot be constant for iso-frequent generators. Hence, the surface finish will vary as well in comparison with iso-energetic discharges.

2. CHARMILLES TECHNOLOGIES (CT)

2.1. The Organization

Charmilles Technologies S.A. (CTSA), a George Fischer +GF+ company has its headquarters in Meyrin Geneva, Switzerland. The new plant (46'000 m^2, SFr. 60 million) with its location in the vicinity of Geneva airport and the European Center for Nuclear Research, CERN, was officially inaugurated in 1988, *Figure 5*. The EDM NC die sinking units and NC wire cutting machines are designed, developed and manufactured at CTSA Geneva. Machine software, programming station software and real CAD/CAM software are also a substantial activity of the company. In addition to the Geneva support, customer services and sales are assured trough six subsidiaries namely CT-LTD (Japan), CTC (USA), CTF (France), CTD (Germany), CTUK (Great Britain), CTI (Italy) and some 60 representatives in many other countries to assure customer services at local domestic markets. Raycon in Michigan state USA, who is specialized in the manufacturing of fine hole drilling EDM machines as well as NASSOVIA, a German based EDM machine manufacturer have recently been acquired by George Fischer +GF+ Schaffhausen (CH). These +GF+ companies are cooperating with the CTSA group.

Besides the six subsidiaries which depend on CTSA (Geneva), six major branches can be distinguished within the CTSA (Geneva) group: Manufacturing, Research & Development, Sales, Marketing, Customer Support, and Finances & Administration. Quality assurance is responsible for maintaining the overall quality of the company's products. In fiscal 1988, CTSA employed 608 employees, where the total consolidated number of employees for CT equals 811. *Figure 6* gives an account of the "CT" mile-stones which have marked our growth in the past and at the present time substantially. In fact, they are cornerstones of today's products, [2].

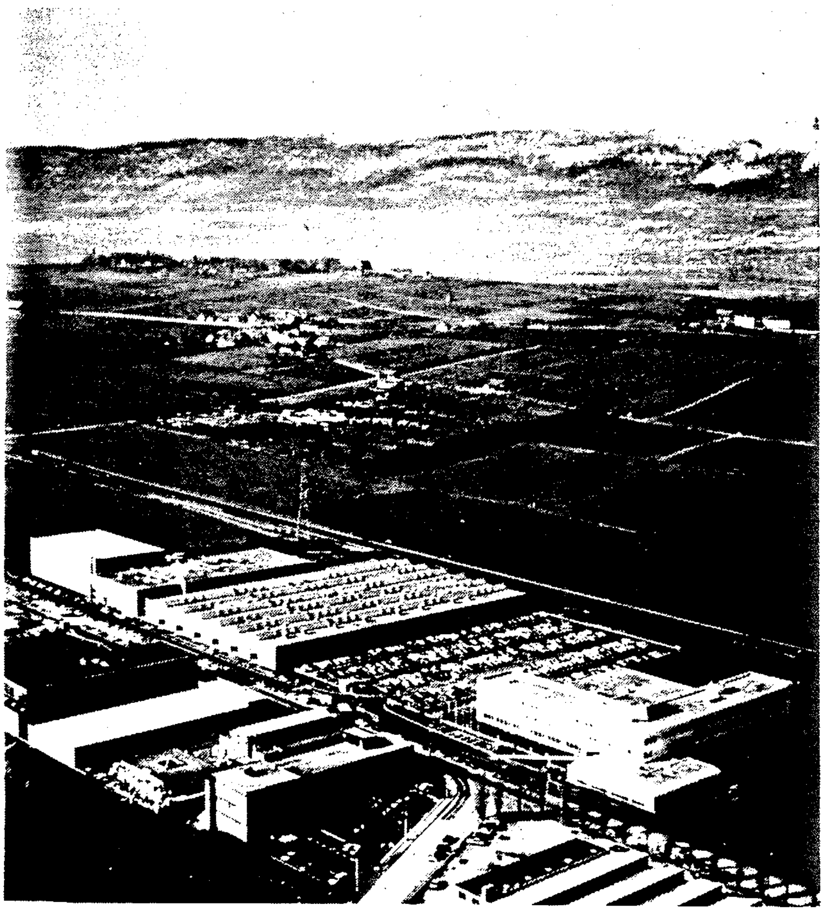


Figure 5. *CTSA new headquarters in Meyrin-Geneva.*

2.2. The Products

The products we offer today rank among the medium and high level precision EDM machines, as well as the software support programs.

From the operator's point of view, the everlasting barriers between EDM die sinkers and EDM wire cutters have been broken. EDM users always have considered wire cutting machines and die-sinkers as two different concepts; they just had sparks in common. Our set of EDM centers, the Roboform (die sinkers) and Robofil (wirecutters) have been realized according to a common concept. These machines are shown in *Figures 2 and 3*. This concept enables the operator to handle either machine with ease, because common operator commands are utilized. This was achieved by standardization and analysis of "machine performance functions" during the machine development stage. Special attention was also given to ergonomics.

ATELIERS DES CHARMILLES SA

1955 FIRST EDM DIE SINKERS

1959 FIRST TRANSISTORIZED GENERATORS

1964 ISO-ENERGETIC DISCHARGES

1973 FIRST EDM WIRE CUTTING MACHINES

1976 PLANETARY EDM'ING

1977 ISOPULSE 80 GENERATOR

1981 FIRST EDM CNC FOR DIE SINKERS (ROBOCUT)

1982 ROBOFIL 552

FOUNDATION OF CHARMILLES TECHNOLOGIES SA

1983 SUPER EDM POLISHING

1984 NEW EDM CNC SERIES:
ROBOFIL 100 - 200 - 400 - 600
ROBOFORM 100 - 200 - 400

1987 NEW HEADQUARTERS NEAR GENEVA AIRPORT:
ADMINISTRATION, R&D, PRODUCTION,
SALES, SCHOOLING, ETC.

1988 FORM-20 (SINKING)

1989 "THOUSAND SERIES" WIRE CUTTING MACHINES

Figure 6. *Overview of CT's historical milestones.*

These EDM centers can also be linked with existing CAD-CAM centers in the design department. The possibilities that exist in the programming software provided are such that linking can be done by a standard interface and selecting one of the standard part programming codes. This is a substantial step towards an easy and user-friendly machining environment.

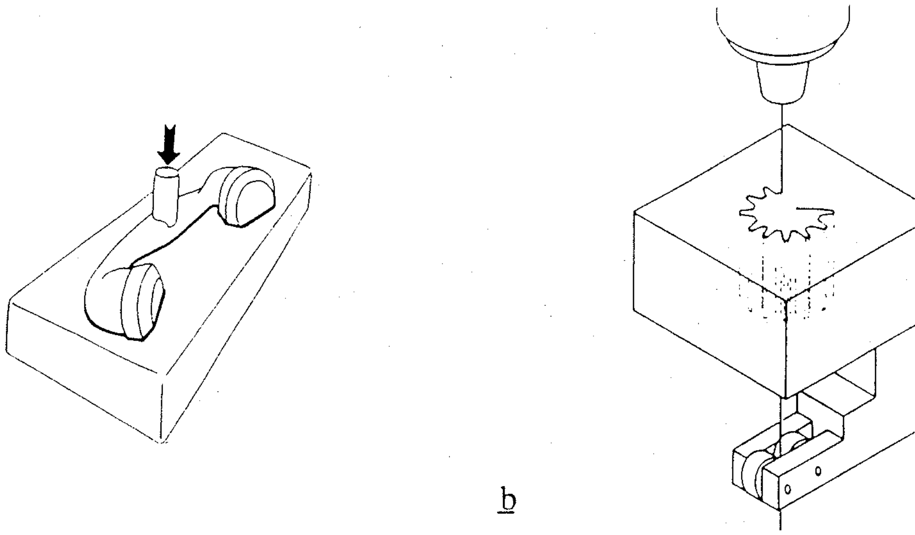
A complete new set of wire cutting machining centers, named the *"thousand series"* to distinguish them from the "100 series" of wire cutting machines was announced and presented during the 1989 EMO tool fair in Hannover, Germany. This new series is designed and built keeping in mind that machining speed and machining accuracy can be combined. We call it *"Speed with Intelligence"*. This will further be dealt with in paragraph 2.2.3.

2.2.1. Principles of EDM

Spark erosion is a thermal process where material removal is being achieved by electrical sparks occurring between a tool-electrode and a workpiece. Both are submerged in a liquid dielectric. In die sinking, *Figure 7a*, a plunging electrode is applied, where for wire cutting, a wire acts as tool electrode *Figure 7b*.

Each discharge develops, within a very short period of time, an amount of energy (0.4 mJ - 12 J) on a very small spot on the workpiece surface. Due to high power density (10^5 W/mm^2 - 10^5 W/mm^2) a minute volume of material may be removed by melting and evaporation. Part of the total energy is also absorbed by the tool electrode; hence, some "tool wear" occurs as well.

Sparks are created by a generator, *Figures 2, 3*. Current level i_e (1 - 150 A), open circuit voltage u_i (80 - 250 V), pulse duration t_i or discharge duration t_e (1 - 3000 μs), and pulse interval t_o are set and controlled automatically. Deionization of the dielectric is partially ensured by the presence of a pulse interval time t_o. If this time interval becomes too short, then "arcing" may occur. A servo system controls the sparking gap. This system must be controlled very precisely in order to avoid too many short circuits and open circuits. It contributes to the efficiency of the process.



a b

Figure 7 a, b. *Principle of the EDM die sinking and wire cutting.*

The liquid dielectric has three major functions:

- Maintaining the pulse energy intensely concentrated.
- Removing debris produced by the process.
- Cooling liquid in the gap.

The type of dielectric depends on the application, wire cutting or die sinking.

2.2.2. NC-EDM die sinking centers

The die sinking NC-EDM centers "ROBOFORM" feature four axes machining (X,Y,Z,C) and enable multi axes machining. These machines are manufactured in several sizes depending on the customer's requirements and applications.

In order to integrate these EDM units on the shop floor, several "integration concepts" have been realized. In section 5, it is made clear how integration is being introduced in Charmilles Technologies' EDM machining centers by providing several options. These machine options must assure that:

- die sinking programming can be performed completely automatically,
- tool and workpiece measurements can be run,
- that particular machining modes can be introduced with ease, and
- tool and workpiece handling can be provided.

a) The integrated strategy for die sinking edm

Figure 8 gives an idea of the new integrated strategy. ROBOFORM die-sinking EDM centers are now designed to operate without close supervision. For this, the machines are to be equipped with integrated strategies and a system of "measuring cycles" capable of compensating for electrode wear during machining. This latter feature is clearly explained in the next section. The integrated strategy enables the operator to easily carry out the preliminary programming of the job to be machined by electrical discharge machining. After the well-known technology data sheets using a graphical presentation, other methods have been introduced, in particular the "technology slide rule".
The integrated strategy presented here is certainly worthy of the name and is developed as follows. As initial parameters are requested :

1. the workpiece-tool combination of materials.
2. the desired surface finish.
3. the final dimensions (machining depth).
4. the frontal area of the tool.

The last of these parameters helps to determine the maximum permissible current, which depends on the current density and the frontal area.

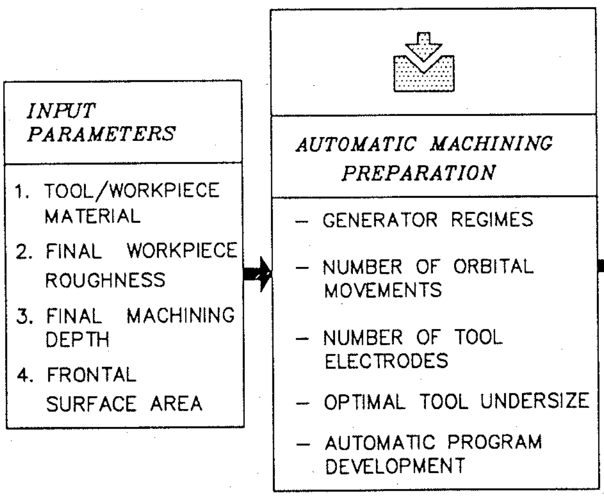


Figure 8. *Integrated machining strategy for die sinking on Roboform.*

After these parameters have been supplied, the microprocessors of the system generate the program, with automatic determination of:

- the number of machining settings.
- the machining time.
- the number of orbital movements.
- the proposed number of electrodes.
- the under-dimensioning of the electrodes.
- completely automatic generation of the program so that the operator is freed from the task of manual preparation of the "PROFORM" program.
- verification run of the program and optimizing the machining parameters.

An additional advantage of this system is the implicit presence of a complete "EDM data bank" which is spontaneously proposed to the user. This data bank incorporates the vast base of knowledge built-up by experts, research workers and, above all, users. During the execution of the process, the effect of the integrated strategy can also be seen in the control of the process optimization, corrections of parameters, etc.

b) Measuring cycles

EDM machining centers, designed for autonomous functioning must also be equipped with an automatic measuring routine. It enables three dimensional automatic measurements for both, workpiece-parts and tool-electrodes prior or after a machine run. In fact, it can be seen as a kind of recognition system for parts and tools. Two measuring options are provided, workpiece measurements and tool-electrode measurements.

- *Workpiece Measurements*

This routine allows the geometric determination of a fixed part in the working environment. Forty eight workpieces can be measured by using an additional measuring probe. The data can be stored in memories for later use and maybe displayed on the CRT when required. Several possibilities are shown in *Figure 9*. For example, the location of corners of the workpiece can be easily determined, or the location of holes or cavities can be detected as well as the geometric center of a workpiece, *Figure 9*. It is well understood that a machined part can also be measured to verify its final required dimensions. This may also be recalled for later use.

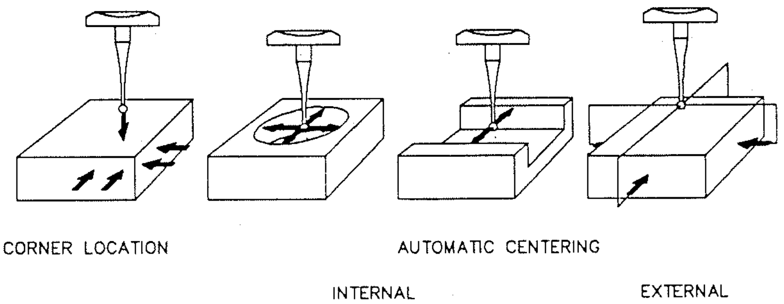


Figure 9. *Measuring cycles for workpieces on die sinking Roboform machines.*

- *Tool Electrode measurements*

The same measuring cycles' software also enables the measurements of the tools with respect to a reference ball. This enables to determine the tool-undersize prior to or after machining as well as the tool eccentricity.

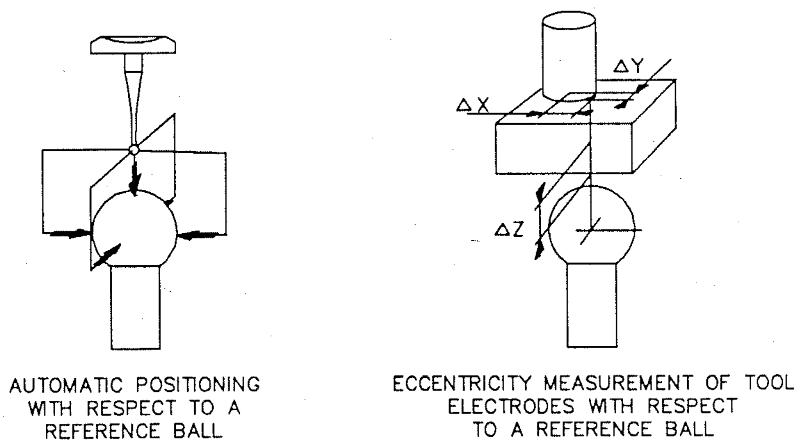


Figure 10. *Measuring cycles for tool-electrodes on die sinking Roboform machines.*

The benefit of this option is that tools to be verified and measured can remain in their tool holder. Hence, random errors introduced by manipulating the tool electrodes can completely be avoided.
The principle of the measurement is given in *Figure 10*. Initially, the reference ball has to be determined. This is carried out by using the same measuring software but applying the measuring probe as explained in the previous section.

Once the reference ball coordinates are known, the tool measurement can be performed, *Figure 10* at the right hand side. Up to fifty tool data can be saved on one file.

It is obvious that tool measurements are necessary for tool wear compensation. Therefore, the measuring routines are provided with four measuring modes in which one are more geometric axes (x, y, z, or c) can be enabled or disabled. For instance, when only the frontal tool wear has to be known, then a measurement along the Z axis is sufficient.

c) "3D" EDM Contouring

Another feature to improve the machining autonomy is the so called "EDM contouring", *Figure 11*. This machining mode enables the machining of complex shapes by applying very simple tool electrodes. In addition, the programming is very convenient. For example, the ARC statement can either be defined as follows:

ARC/DIR,XC,xc,YC,yc,X,x,Y,y or,

ARC/REV/YC,yc,ZC,zc,Y,y,Z,z,L,l,H,h,E,e or,

ARC/ZC,zc,XC,xc,Z,z,X,x

Here, *DIR* defines a clockwise movement direction, and *REV* defines the counter clockwise direction. The pairs of coordinates *XC,YC,* or *YC,ZC,* or *ZC,XC* define the center of the circle with respect to the main reference plane. The pairs of coordinates *X,Y,* or *Y,Z,* or *Z,X* define the end point of the tool movement in the main plane. *L* and *H* are the coordinates of the end point of the arc perpendicular to the main reference plain such that a super-imposed movement can be carried out proportional to the basic circular movement. It allows to create helicoidal movements of the tool electrode.

Finally, *E* defines the machining regime. This variable refers to the entire set of process parameters as for example the discharge current value i_e, the pulse duration t_e, pulse interval time t_0 etc.

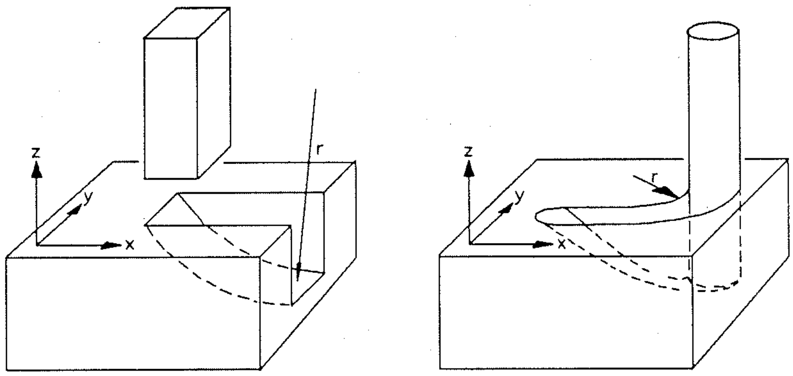


Figure 11. *Example of 3D EDM Contouring.*

Figure 11 shows two examples which emphasize that the programming is very easy. The example shown on the left hand side of the figure is defined by the following statement:

ARC/REV,ZC,0,XC,25,Z,-15,X,35,Y,0

In this example, the *ARC* statement defines a counter clockwise circular displacement with reference to the main plane, in this case the plane X-Z. The movement is defined by the center of the circle *(ZC,0,XC,25)* as well as the end coordinate of the tool *(Z,-15,X,35,Y,0)*. No additional displacement is given with respect to the Y,Z plane. As shown above, one statement is sufficient to describe an electrode movement, including generator regimes and machining parameters.

The second example on the right hand side of Figure 11 is defined by the following statement:

ARC/REV,XC,5,YC,25,X,30,Y,30,Z,-15

As the figure shows, a simple statement can create a complex tool path.

d) Tool and workpiece handling

EDM machining centers incorporated in a flexible manufacturing system must be provided with a tool and workpiece handling system to allow flexible part handling. A tool and part handling system must communicate with its peripherals to search and to take the required parts at any moment.

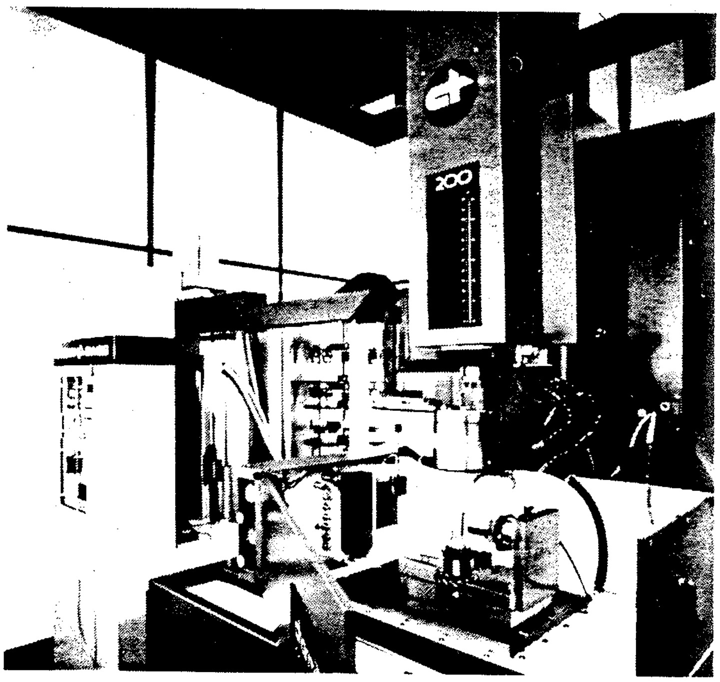


Figure 12. *EDM machining Center Equipped with a Universal Handling Robot.*

To satisfy already a certain market demand, a system has been provided which shows an EDM machining center already linked to a universal robot handling system, Figure 12. It is a single handling device for tools and workpiece parts with a fifty position tool/part changer. It improves the production flexibility and can be programmed with ease. Communication is performed by simple handshake commands. Tool and workpiece clamping and fixturing is assured by applying the pneumatically controlled S-40 part holders. The system is designed such that it can easily reach the working tank as depicted in Figure 13. When integrated at the shop floor, it can be imagined that the "EDM-tool cell" will be supplied with new tools coming from an accompanying tool manufacturing cell also equipped with a universal robot system.

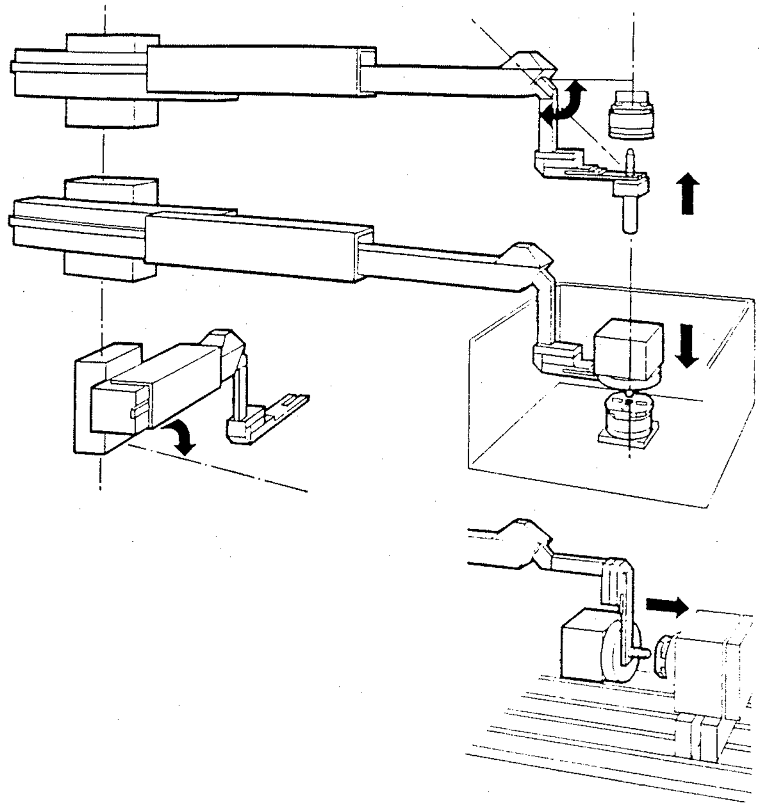


Figure 13. *Example of robot arm movements for tool and workpiece loading.*

Although the examples discused above do not meet yet completely the CIM philosophy as we dealt with (infra), it shows however that manufacturing automation and flexibility is underway.

2.2.3. NC-EDM Wire Cutting Centers

The ROBOFIL machines are built around the same concept as the ones discussed before. As the mechanical structure has common parts, so does the machine programming language. This allows a user-friendly machine operation. As in the ROBOFORM die sinking machines, an EDM database is also provided internally in the machine in which machining performances are stored in function of the material to be cut. To facilitate programming of complicated workpiece shapes, the PROFIL+ programming language as well as other additional software tools can be used. A ROBOFIL wire cutter is therefore equipped with a P.C. programming station. It is part of the standard wire machine equipment. After programming on the PC work station, a conversion (post processing) of the developed program into the I.S.O. standardized syntax structure, ("G commands") is executed. Some examples are given in Figure 14.

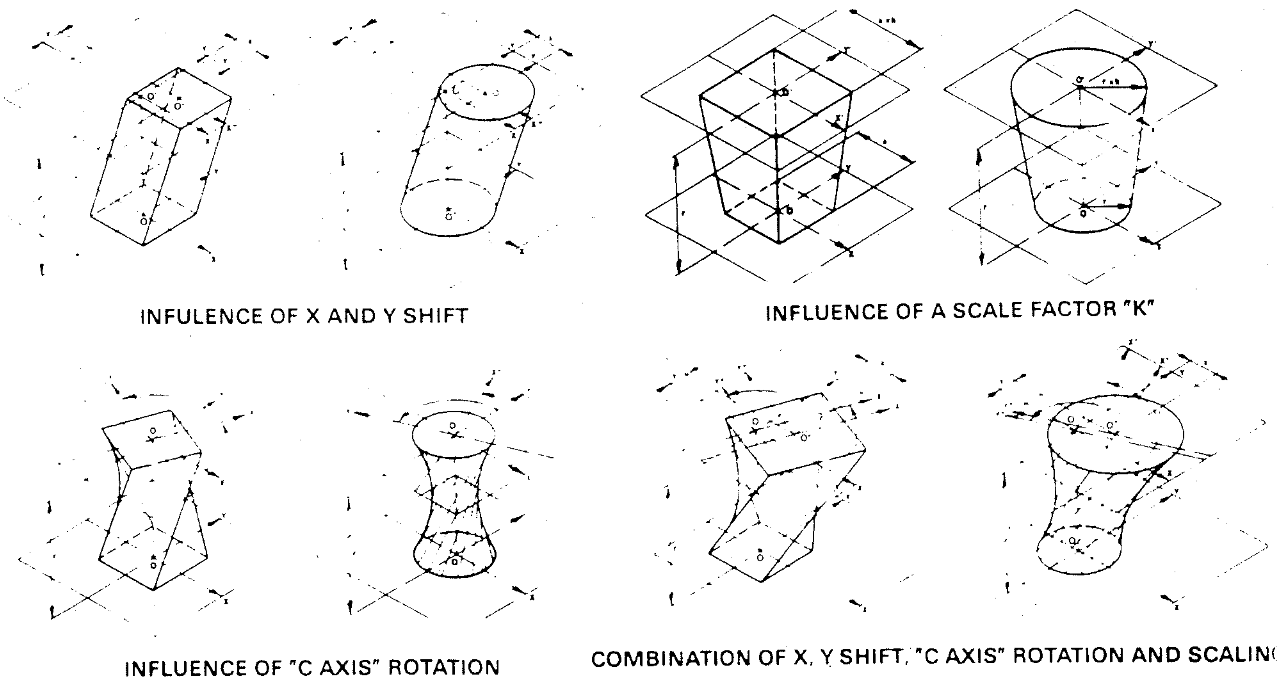


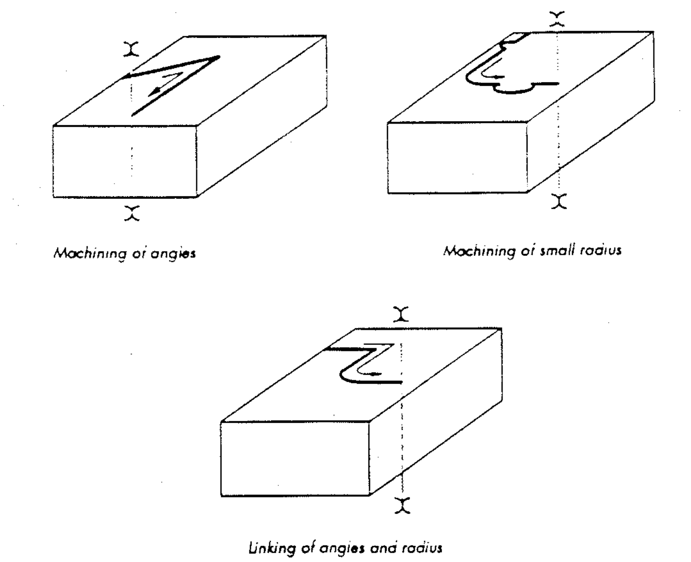
Figure 14. *Example of ruled surfaces, (wire cutting).*

In this set of pictures, several ruled surfaces are generated by the wire cut program software (PROFIL+). The examples below show how the software module "TWIST" can alter the entire shape according to the applied scaling or twist-angle.

A complete new set of wire cutting machining centers, named the *"thousand series"*, shown in Figure 3, to distinguish them from the "100 series" of wire cutting machines was announced and presented during the 1989 EMO tool fair in Hannover, Germany. This new series is designed and built keeping in mind that machining speed and machining accuracy can be combined. We call it *"Speed with Intelligence"*.

These machines have been developed to satisfy our customer needs in terms of machining speed, accuracy, reliability and user-friendly programming and control. A very important feature is that high machining speed and full accuracy can be obtained due to the combination of fully adaptively controlled strategies stored into the machine. This is shown in Figure 15.

This figure illustrates a series of machining possibilities which can be performed. For example, When machining an inclined plane, or a workpiece with a variable thickness as shown in Figure 15, wire machining speed, flushing pressure and the discharge current intensity are adjusted adaptively to assure the fastest possible machining speed with a maximum of workpiece accuracy.



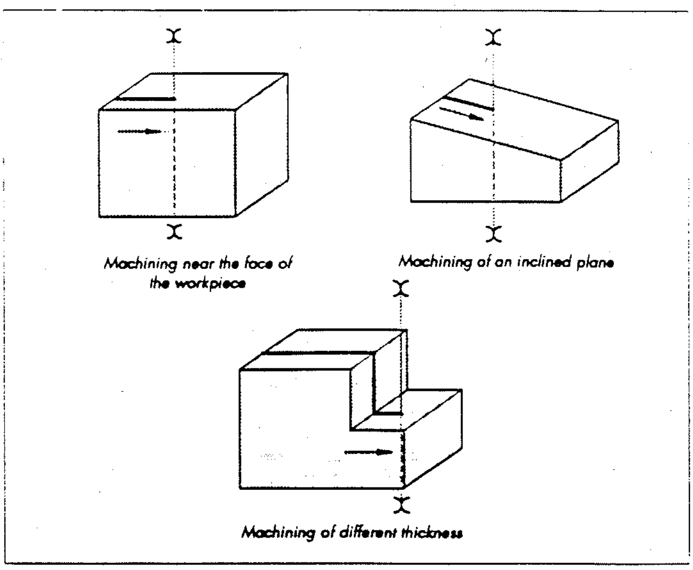


Figure 15. *Machining Examples on the ROBOFIL 2000 wire cutting intelligent machine.*

These machines are also loaded with the CTSA "EDM Technology Data Banks" which allow the user to machine a vast number of various workpiece materials.

2.3. The Results

Regarding to the activities of the last decade, one might recognize a positive increasing trend in facing the future. This is made clear by the investments made by the company in human resources, R & D investments, and new CT subsidiaries in the U.K., Japan and Italy. Our intentions and actions to face the European Common Market, with its target 1992 are also currently taken into consideration, in order to be prepared as well.

3. GENERALITIES ABOUT THE CT R&D DIVISION

The CTSA Research and Development Division (R & D Division) consist of several departments and services as :
Machine Design Department, Machine Maintenance Department, Software Development Group, Numerical Control Design and Development Group, Electronic Development Group, Industrialization Group and the Applied Research Department.

In addition, the Legal Department takes care of patent matters and legal affairs. The R & D main activity is design and development of new products, hardware and the accompanying software. This of course in collaboration with the Marketing Department, and indirectly with customers as well. Besides this, a large effort is paid on the maintenance and updating of existing products. This in order to satisfy customer demands and to strive for better and more advanced machine technology.

4. GENERALITIES ABOUT THE APPLIED RESEARCH DEPARTMENT

Within the R & D Division, the Applied Research Department is focusing on future means and technology. Therefore, it is necessary to have an active and efficient team, who has also many links with the "outside scientific world". Hence, the department has an internal and external research activity, *Figure 16a*.

The **external activity**, drawn in *Figure 16b* has its connections with worldwide universities, technical scientific committees and industrial partners.

The **internal activity** is taken care by a **"Fixed Team"** of engineers, scientists, mathematicians, etc. Regularly, colleagues of the R & D division, named **"Temporarily Team"** in *Figure 17* are joining the fixed team to improve communication and to enhance the creativity of the individual. After a while, they leave the research department to rejoin the R & D division in a particular service team or development group, *Figure 17*.
This allows **simultaneous engineering**, in which common thoughts, ideas, and sometimes dreams might come through and evolve into real realizations. These prototype-based realizations are then transferred to the R & D division, of course with mutual agreement of the Marketing specialists.

Since long, Charmilles Technologies S.A. has a very fruitful and intensive collaboration with reputated research institutes and research centers, and this on a world-wide bases. In *Figure 18*, an overview is given of these laboratories. It is intended to prevent overlapping in the research topics to be dealt with. Normally, each research center has its typical specialization, which goes from fundamental statistical analysis of discharges, over EDM application related matters, towards EDM software related issues and process analysis instrumentation equipment.

On the figure, one can distinguish seven areas were EDM ore EDM related research is performed with CTSA sponsoring and assistance.

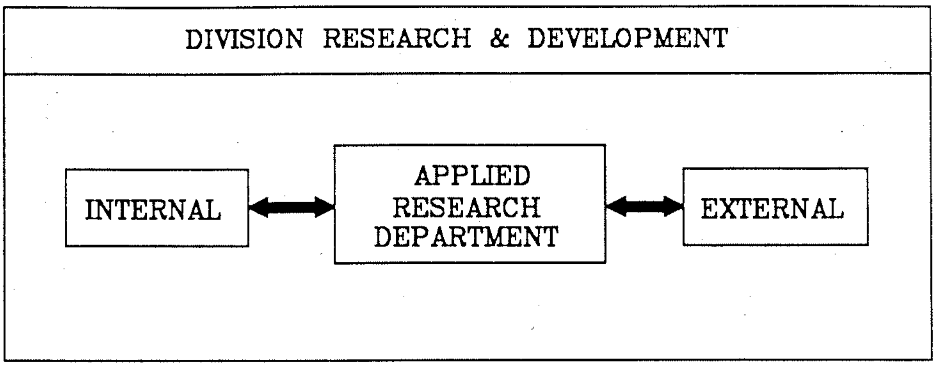


Figure 16a. *Structure of the Applied Research Department (CTSA) belonging to the R & D division.*

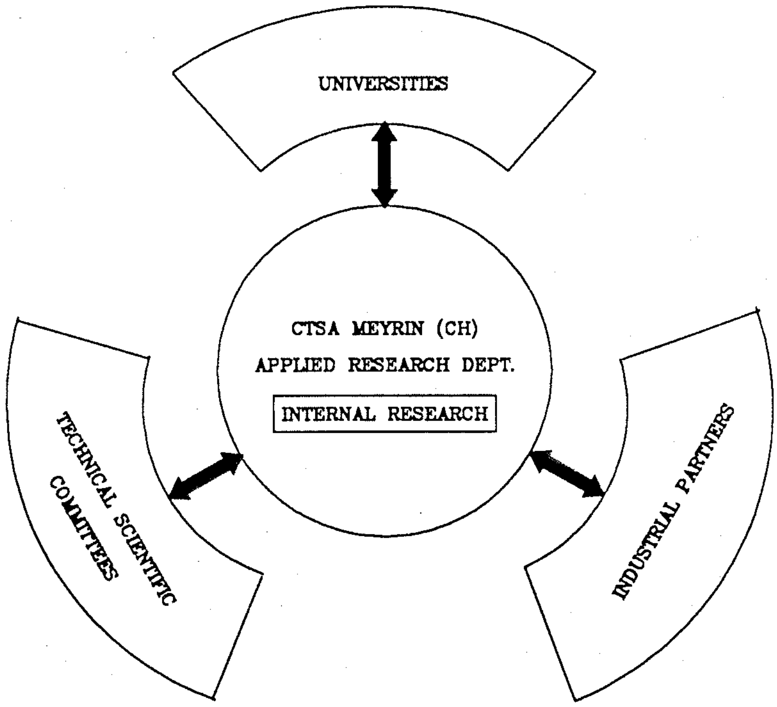


Figure 16b. *Interactions of the Applied Research Department (CTSA) with external institutions.*

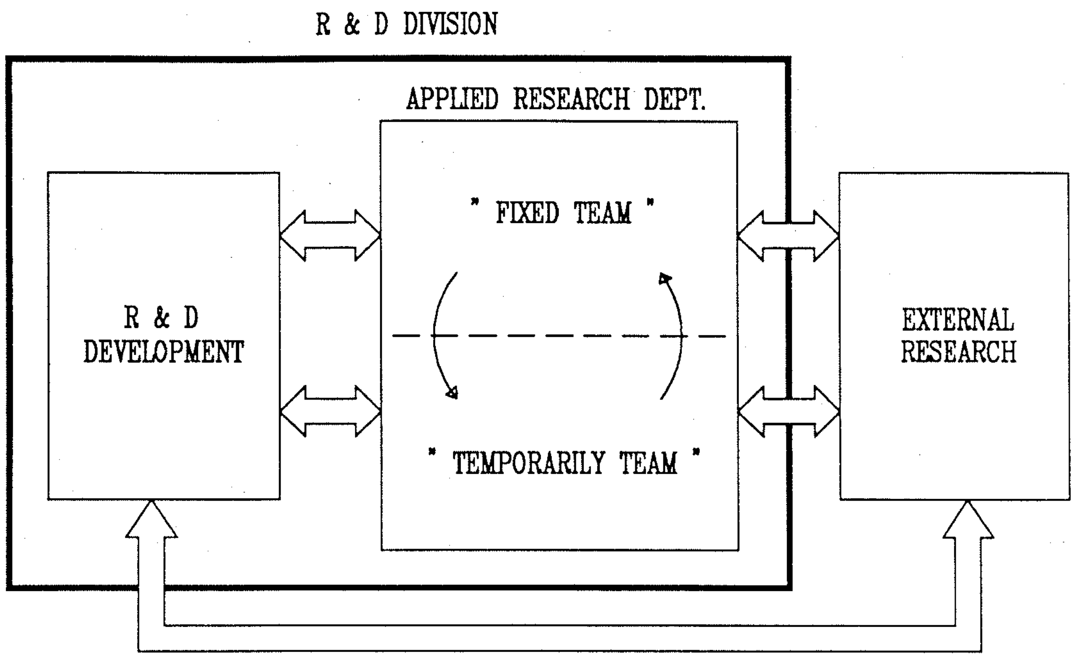


Figure 17. *Organization of the Applied Research Department.*

5. FUTURE TRENDS

Electric Discharge Machining (EDM) is shifting, more than ever before from its island of "Non-Traditional Machining" towards the broad sea of automated manufacturing. Spark erosion often adored by mechanical engineers and machinists for its unique removal principle has now its own niche in the mechanical engineering business.

By others, it has been criticizing for its relatively slow stock removal rate and the skill required to master these machines properly. Nevertheless, in some cases it is the only commercially and technically attractive machining alternative.

Indeed, a number of applications would turn out to be too expensive are almost impossible to be carried out if EDM would not exist.

External Centers for EDM research

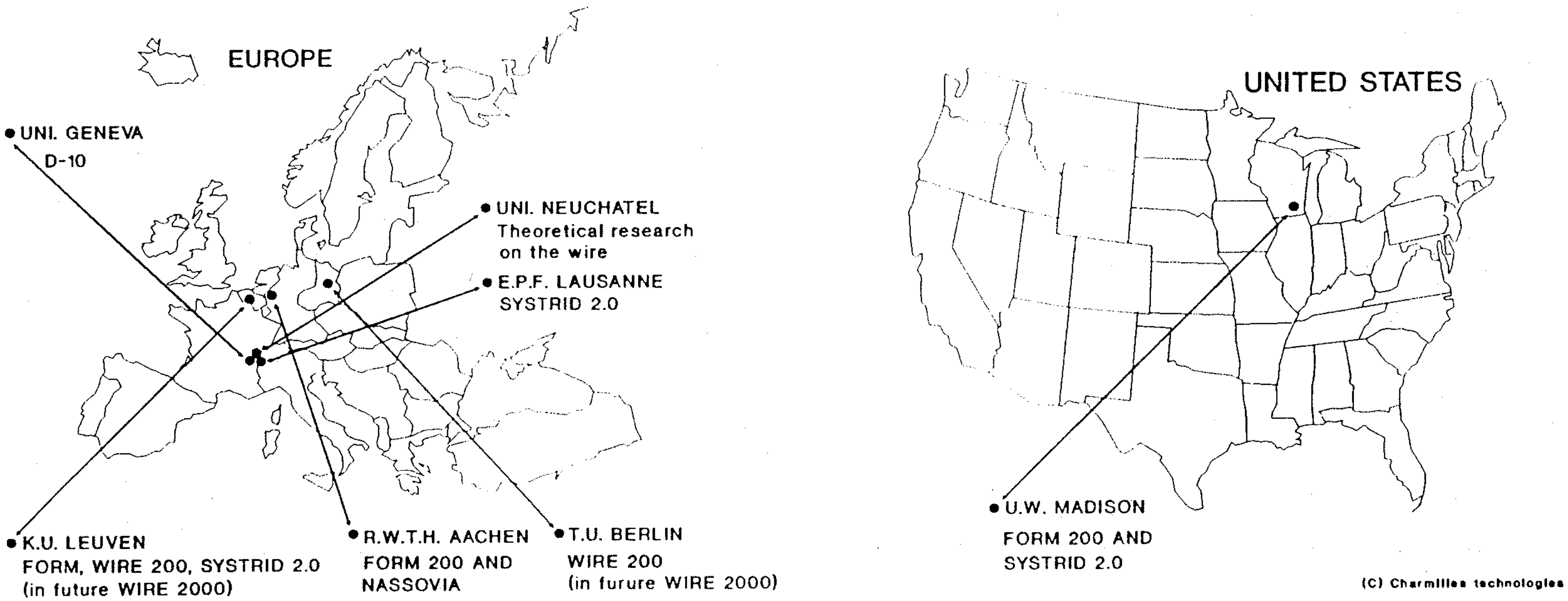


Figure 18. *Location of EDM Research Centers Collaborating with CTSA.*

Whatsoever, it is a fact that EDM being classified in the "non-traditional machining chapter" is now breaking this frontier by entering and integrating itself at the machine shop floor.
This involves that EDM-machining centers must be designed such that the communication problem can be resolved. The final objective is to improve the overall machining efficiency of the EDM process. This is one of our major concerns for our customers. By overall efficiency, it is meant that the EDM unit runs independently and reliably (i.e. machine autonomy), has an own supervision system for tool and workpiece flow and handling, has been provided with EDM skill and experience (stored in internal data banks), and has communication capabilities. Briefly, its autonomy must be assured.

An EDM cell must therefore be able to communicate with other machines. Hence, suitable communication standards must be introduced.

5.1. Communication Networks

Due to the high investments required for translators to connect computer systems and peripherals, a substantial effort has been noticed in developing international communication standards. It is in this context that the International Standards Organization (ISO) has developed a computer network reference model for Open Systems Interconnection (OSI) [4], [5]. It can be viewed as providing two primary classes of service or functionality to an application, i.e. the interconnection services and interworking services.

Interconnection service:

The interconnection service is responsible for establishing and maintaining the data pipeline that allows two applications to exchange data. The protocols that provide the interconnection service provide technology independent, reliable data transfer between cooperating computer systems. These protocols are relatively independent of the specific types of applications which are supported. **They deal with the characteristics of the physical elements of the network such as transmission speed, error detection and correction, network topology and transmission packet sizes.**

Interworking service:

The interworking services also defined by the ISO model allow cooperating applications to create application programs that use the network to accomplish meaningful work. **The interworking services tend to the semantics, syntax and structure of the application data. These kind of protocols tend to be dependent on the particular types of applications that they support.**

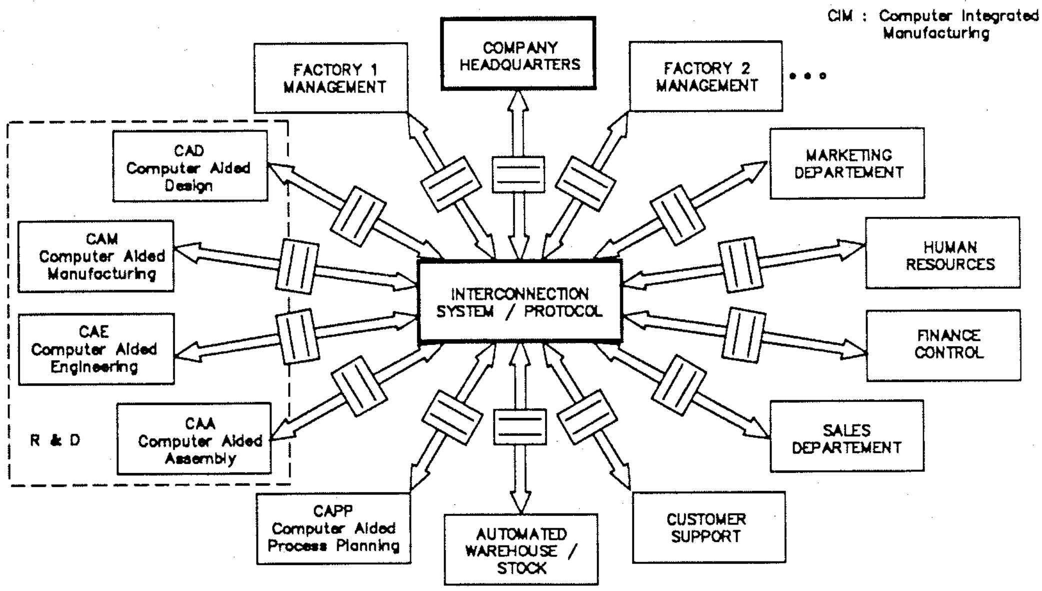


Figure 19. *Factory of the Future with CIM included.*

In order to show that the system integration philosophy is now coming through, I refer to the Manufacturing Automation Protocol (MAP) [6], [7]. MAP, the well known communication network protocol developed and introduced by General Motors in 1981. GM selected the ISO model as the basis for the network and defined the protocols at each layer of the model, intending to have a system network for the "Factory of the Future".
MAP is a device independent Local Area Network (LAN) specified at the interconnection level and based on the ISO standard discussed before [4].

Since the initiation of MAP in 1981, the "Programmable Devices Committee" of GM released several documents concerning the protocols. The last specification, which was released in may 1987 deals with the Manufacturing Message Service (MMS), [8]. It includes basic network functions, synchronization, robotic control, job scheduling, operator communication, numerical control, file transfer and management to indicate the most important items. The most recent edition of MAP, version 3.0 has been released early 1988.

Figure 19 explains the Computer Integrated Manufacturing (CIM) philosophy. General Management, Manufacturing, R & D, Customer Support, Marketing, Financial Dept., Sales, and Human Resources are linked together by a communication network to make available shared data among the several departments in the factory. This should lead to shorter production times, reduced inventory, consistent quality, less need for human intervention and management flexibility to respond quicker to market changes.

5.5.1. Actual organization

Figure 20 gives an overview how most of today's EDM-jobs are performed. The tool design is either carried out by a classic approach using drawing rulers and drawing tables or by using a Computer Aided Design (CAD) system. A lot of skill is already introduced at this level, because it is often the EDM operator himself who runs through this whole tool design cycle. The tool manufacturing is then performed by applying several production techniques using milling machines, turning units, drilling machines, grinders, or even other machines. Finally, the tool arrives where it belongs, in the tool chuck holder. This is performed by a flexible tool/workpiece transportation system which receives his information from the Computer Assisted Process Planner (CAPP).

An actual concept is shown in *Figure 21*, in which Charmilles Technologies' EDM machining centers are integrated. In this configuration, the EDM production machines are integrated in a Computer Aided Design - Computer Aided Manufacturing (CAD-CAM) system that is already operational at the customers factory shop floor. The central CAD-CAM group operates as a programming center. The set of machine tools (EDM machines, NC machines, milling machines and screw-cutting lathes) can communicate with the central

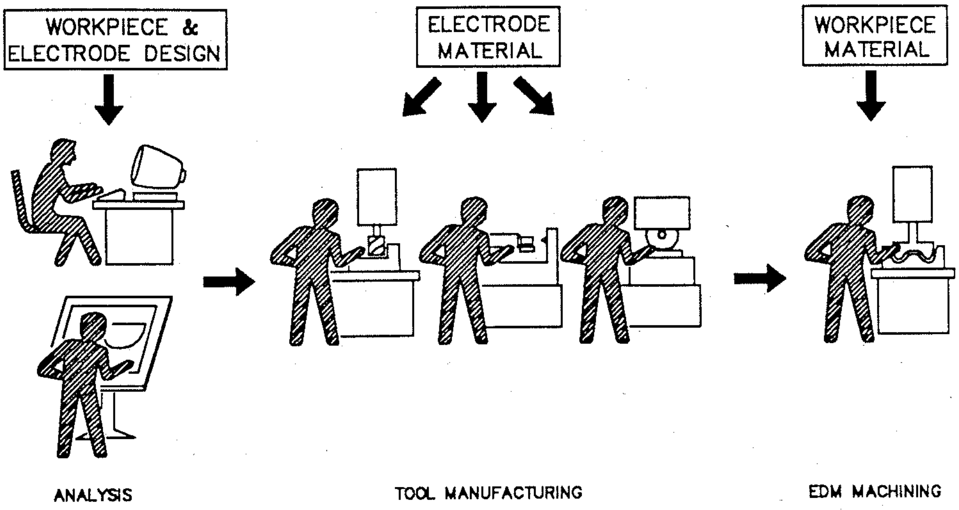


Figure 20. *Product Flow During Work Preparation.*

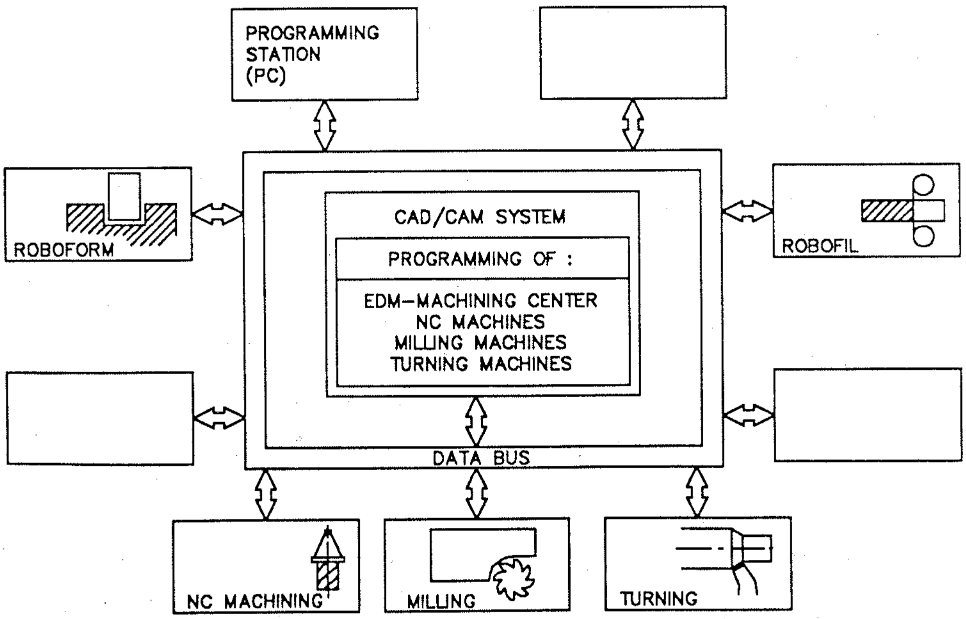


Figure 21. *Integration of EDM machining Centers and others into a CAD-CAM system.*

CAD/CAM system by means of a multi-user interface or Local Area Network (LAN).

In the example below, machines other than EDM machines are also shown. The Programming Station (Personal Computer [PC]) also takes part of the ring.
Each machine is connected to the network by means of a serial interface. Preparation of the program may be carried out on the CAD/CAM system or on the programming unit linked to the network. For example, the PROFIL+ software can also be used for programming NC milling machines. *Figure 22* gives a synopsis of the data banks that may possibly be consulted. Personal and standard "EDM data banks" are available.

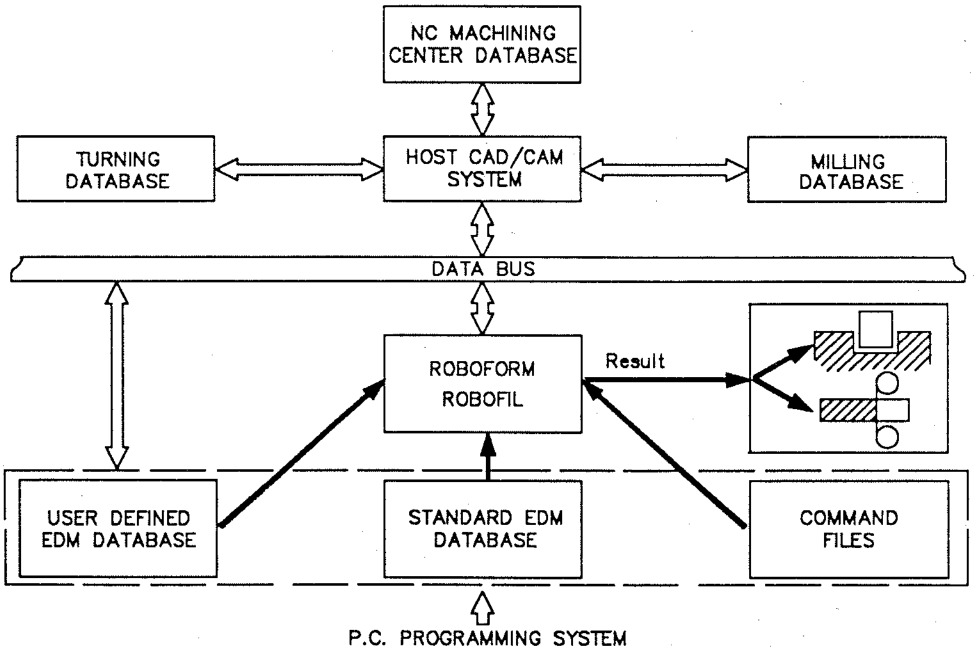


Figure 22. *EDM databases that can be used on Roboform/Robofil machining centers*

5.1.2. Future Organization

Machine integration without improving the machine's autonomy does not make sense and can hardly commercially be justified. It indicates that EDM units as well as other "traditional machine units" must be designed and equipped for it.

As the general overview of the "Factory of the Future" was presented in Figure 19, Figure 23 illustrates a general lay-out of a possible shop-floor or a manufacturing plant design. Indeed, as shown in the first figure, the CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAE (Computer Aided Engineering) and the CAA (Computer Aided Assembly) services are considered to be part of the R & D department. They can of course be shared by other departments as is often the case and which is also one of the aims of the CIM philosophy.
The concept of Figure 23 shows that the "R & D" facilities can communicate with the manufacturing and assembly divisions.

As depicted in Figure 23 the Computer Aided Process Planning unit (CAPP) is connected to the CAD-CAM system, the CAE and CAA units. The CAPP masters the data flow, workpiece and tool transportation to the proper machining stations, in this example turning, milling, grinding and EDM machines. In fact, the CAPP can be seen as the plant manager assuring a reliable and flexible plant organization. The Computer Aided Tool Design (CATD) cell, which can be part of the Computer Aided Engineering unit may also be provided for electrode-tool design. The connection path further serves to allow bi-directional machine communication.

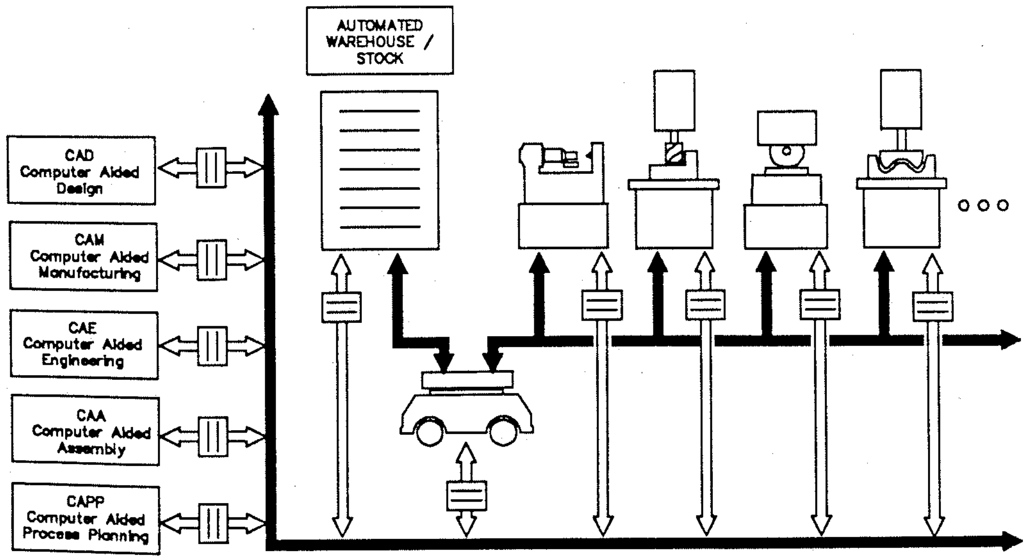


Figure 23. *General Lay-Out of Machining Autonomy Improvement.*

As *Figure 23* shows, an automatic warehouse/stock (tooling center) is also provided which receives and sends tools, proper to each machine in use. This is assured by a mobile unit (flexible robot system).

As has been discussed earlier, the CIM concept (machine integration and communication on the shop floor) is being introduced in Charmilles Technologies' EDM machining centers by providing several options. These machine options must assure that:

- die sinking programming can be performed completely automatically,

- tool and workpiece measurements can be run,

- that particular machining modes can be introduced with ease, and

- tool and workpiece handling can be provided.

Details can be found in par. 2.2.3, 2.2.4 and [9].

5.2. The machining of electrically conductive ceramics

The machining of electrically conductive ceramics is now possible on CT's EDM centers, wire and die sinking as depicted in *Figure 24*. These pieces have been machined on Robofil 200, showing extremely good results on surface finish and cutting speed.

Die sinking EDM in which a plunge electrode is used, *Figure 7a*, is from the physical point of view identical to the wire EDM machining process, *Figure 7b*. One may state that any material which can be wire cut, can also be machined by die sinking and vice versa.

It is known however, that die sinking is often more complicated to master than wire cutting is. This is certainly the case when complex workpieces have to be machined.
The large number of process parameters involved as well as the complexity of the tool electrode may be seen as the major reasons for it. As an example, a complex three dimensional tool, featuring a large tool-workpiece contact surface

may substantially influence the process stability. To compensate or reduce this loss of process stability, sophisticated process control strategies are required. It is obvious that a straight cylindrical wire electrode is easier to control from the point of view of process stability.

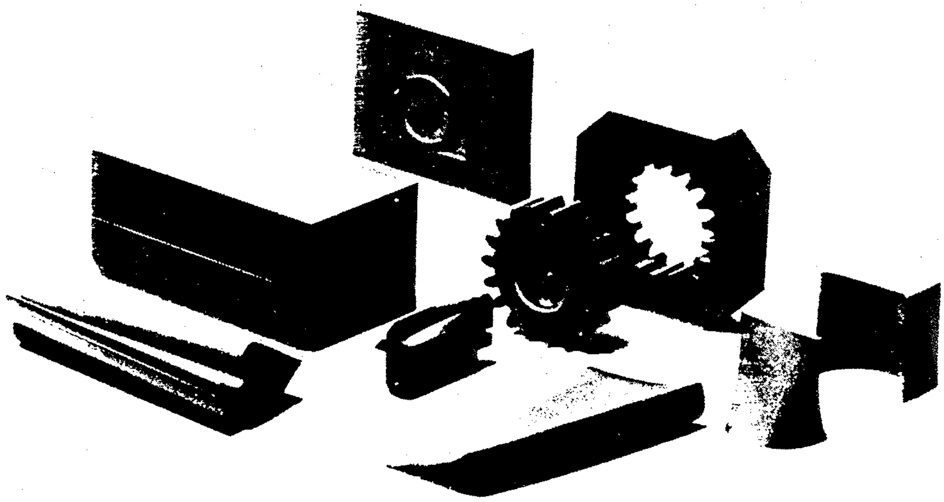


Figure 24. *EDM Machining of ceramic pressing dies, casting moulds, and wear parts.*

From what has been said, it yields that the experienced ceramic materials can a priory also be machined by die sinking EDM. One must however be aware of the risk involved when die sinking conductive ceramics.

Suppose that the electrical conductivity of the ceramic workpiece to be machined can not be guaranteed throughout the entire workpiece volume. It may happen that machining starts and goes on smoothly, but at a particular moment, machining would not progress anymore due to a lack of local electrical conductivity. It would cause tremendous problems, because the machine's control strategy would interpret this phenomenon, faulty as an "open circuit condition" though, in reality tool and workpiece would be mechanically in contact with each other. An open circuit condition means a too large gap to allow gap voltage breakdown. Hence, an additional tool feed would be imposed, to reduce the gap width, crashing the electrode and workpiece together. It would either damage the machine's servo ram, the electrode or the workpiece itself.

This kind of problems is less important for wire cutting applications. In case of conductivity failure of the workpiece, the wire would break, without any damage of the machine.

Therefore, whenever conductive ceramics have to be machined by die sinking EDM, it is absolutely required to know a priory whether the piece to be machined is sufficiently conductive. Attention must also be paid to the workpiece rough surface layer. Oxidation layers on the upper workpiece surface are often less conductive then the internal ceramic material itself. This might complicate the EDM process initiation.

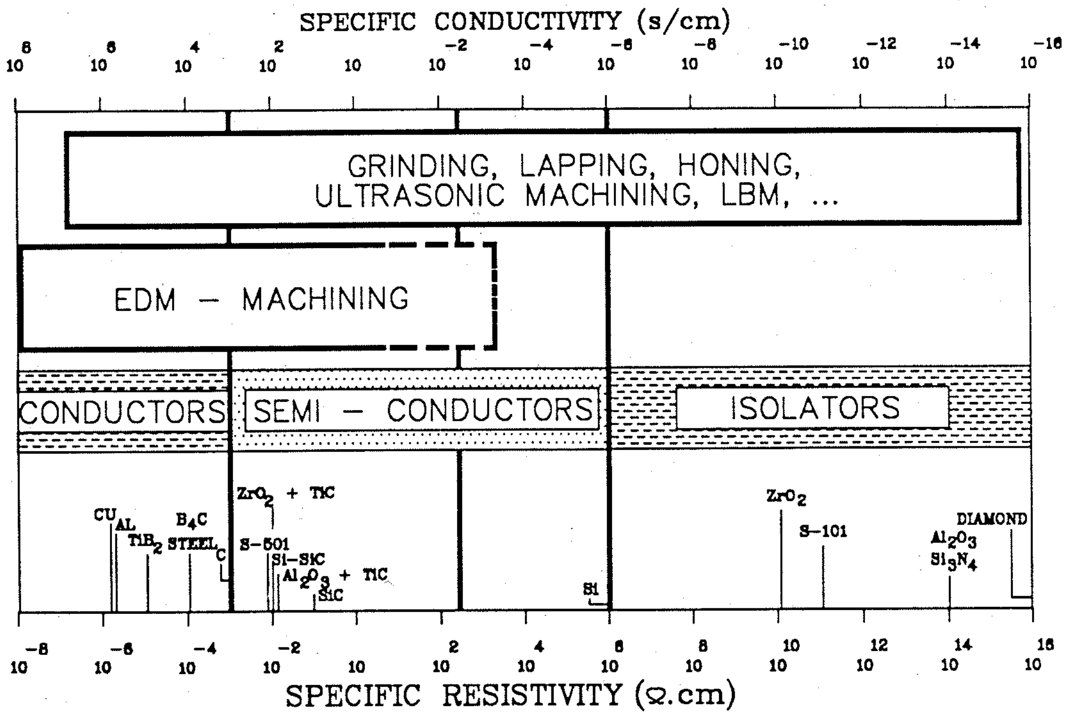


Figure 25. *Specific electric conductivities of various materials.*

Figure 25 shows the specific conductivity of various materials, marked on the figure. One may remark that the actual machinability threshold is moving towards materials which feature a relatively high electrical resistance. It means, that when time goes on, more "exotic" materials can be machined by non traditional machining methods, as for example spark erosion.

6. CONCLUSIONS

This paper gave an overview of several EDM related matters. A brief introduction was given dealing with some historical aspects of the EDM evolution. The CT company was presented, in particular the R & D division and the Applied Research Department.

The various products were presented as well. A large part dealt with the evolution of flexible manufacturing, in particular in the field of Electrical Discharge Machining (EDM). It was shown that substantial efforts have been noticed in defining and establishing communication networks and protocols for computer systems and peripherals.

In order to improve the overall machining efficiency of EDM machining centers, it is unavoidable to integrate these machines at the shop floor. It allows improvement of the machine autonomy and stand alone runs of these machines in save conditions. Therefore, communication and automatic part handling are very important.

The actual situation on how the material flow and data flow are executed were discussed as well a future estimation of the situation was presented.

To show that Charmilles Technologies' EDM machining centers are already provided for job-floor integration, several machine characteristics were discussed. I.e. the integrated machine strategy for die sinking EDM'ing, measuring cycles for tool and workpiece recognition, 3-D EDM contouring and finally tool and workpiece handling by a universal robot system.

In a last paragraph, the machining of electrically conductive ceramics by EDM was discussed. It was shown that actually, these ceramics can readily machined by CT's die sinkers and wire cutting machines. A special note was given on the importance of the specific electric conductivity of the ceramic parts, in order to assure reliable machining.

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8. LIST OF FIGURES