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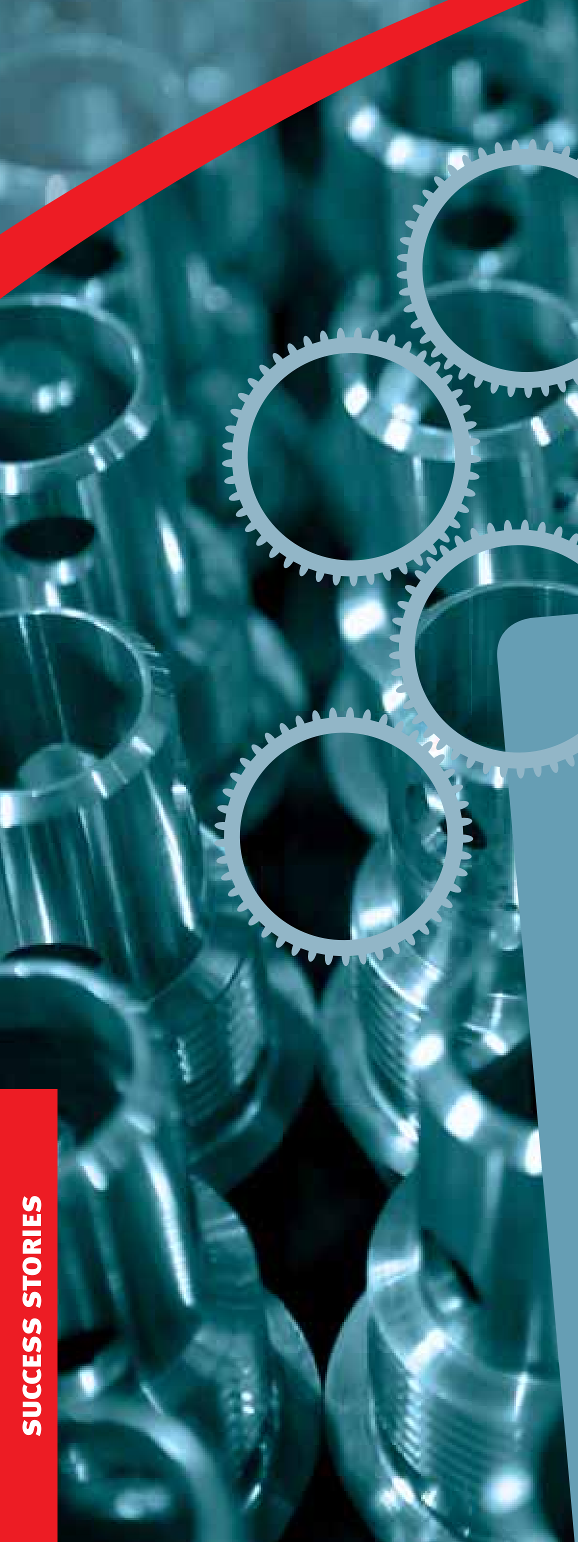

Transforming the tools of production

Strategy for a sustainable European machine tools industry

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Transforming the tools of production

Strategy for a sustainable European machine tools industry

Directorate-General for Research, Industrial technologies
2009 Unit G2 'New generation of products' EN

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EU supports change in a vital sector

Machine tools are key to an enormous range of production processes. Their manufacture has long been a great strength of European industry. But today, there is a pressing need to introduce new technologies in order to meet changing societal demands and stay ahead of global competition.

Much of the groundwork for a strategy to transform the European machine tools sector was laid in the MANTYS Thematic Network, an initiative supported by the EU under the Industrial Technologies Priority of its Fifth RTD Framework Programme (FP5 – 1998-2002).

This four-year initiative was launched as part of a drive to combat the threats of market globalisation, increasing competition from low-wage competitors, and rapidly reducing life-cycles for all kinds of manufactured products. It recognised that future success would depend on the ability of industry to absorb the latest technology and respond quickly to the demand for increasingly customised products and solutions at highly competitive prices.

Leadership at risk

The effect of these pressures on the machine tools production is of particular concern. Although European suppliers continue to meet the majority of global demand (ahead of China), their share has declined markedly over recent years. The objective of MANTYS was to strengthen this leadership position by coordinating research across the EU, maximising efficiency and ensuring that results could be exploited as fully as possible.

Led by the European committee for co-operation in the machine tool industries (CECIMO), MANTYS provided a forum for participants to share knowledge relating to technology, socio-economic issues, sustainability and quality-of-life aspects of manufacturing. From a core consortium of 30 prominent institutes, research laboratories and industry associations, it evolved to link more than 80 individual research projects. Its foresight reports helped to guide the content of calls for proposals in FP6, and paved the way for the creation of the Manu*future* European Technology Platform (ETP).

Manu*future*, officially launched in December 2004, offers a means for industrialists, academics and policy-makers to share experiences and contribute ideas to the formulation of a strategy to maintain and enhance European manufacturing strength, underpinning continued economic growth and job creation.

With the benefit of its broad membership, now joined by some 30 comparable networks at national/regional level, Manu*future* was able to provide the Commission with a roadmap and a vision for further development up to 2020.

Strategy consolidated

Various initiatives in FP6 and the first call of FP7 have continued the work of creating an implementation plan for the sector. The projects in this EU machining cluster (several of which are outlined in the following pages) are of great strategic importance because:

- for the first time, they represent a European critical mass;
- the thrust of the research activities has shifted from specific machine-tools or mechanisms, towards a more general capacity for production;
- there is simultaneous focus on processes (new tools, machines, etc.), on the integration of these into the factory environment (robots, new systems of communication between machine tools, etc.) and on business-level relations between producers and their customers (new business concepts, training/marketing packages and dissemination activities);
- breakthroughs have already been achieved in a number of key production technologies.

Extending the international collaboration beyond the EU boundaries – as seen in the Intelligent Manufacturing Systems (IMS) scheme – remains a longer-term objective to facilitate such aspects as standardisation, IPR protection, and global design. This will be addressed in future FP7 calls. Meanwhile, the results to date represent solid progress in providing an RTD framework for a traditional sector largely dominated by SMEs. They form a springboard for the development and innovation that will underpin progress towards a sustainable and competitive knowledge-based European industry.

Research for the NEXT generation

The Integrated Project NEXT is the main FP6 vehicle for advancing the overall roadmap for the machining sector. Its goal is to commit the main stakeholders in the European production equipment industry to the achievement of radical innovation in diverse fields – from machine design, construction and patterns of use, to the adoption of alternative technologies and new approaches to education and training.

High speed parallel kinematic (PKM) robot for pick-and-place tasks developed in collaboration between FATRONIK-Tecnalia and LIRMM (CNRS).

NEXT spans the complete value chain, bringing together research centres and industrial companies that produce or use most of the machine-tools in Europe. The consortium comprises 23 partners from nine countries, under the coordination of Spain's FATRONIK-Tecnalia. They are supported by more than 40 prominent organisations, which form the project's Industrial Board and Research Council.

Closely linked to the Manu*future* European Technology Platform, this initiative is the first example of combined public/private funding for the Implementation Plan of a Strategic Research Agenda. It is also supported by Member State governments and the nationally-financed EUREKA scheme, as well as by the KUTXA Bank, Spain, and the European Investment Bank.

Five tracks

The research is divided into five separate sub-projects, or tracks, combined in a matrix structure by supporting technologies: production processes, monitoring and measurement, adaptronics, new materials, new architectures, controls, simulation and interfaces. Three of the tracks are technological in nature, while the remaining two are economically oriented.

To ensure a consistent system view, the partners are grouped into multidisciplinary teams, the activities of which focus on carefully selected prototypes and demonstrators embodying a broad range of aspects relevant to the next generation of manufacturing systems. Details of the exploitable results are presented on the project website, but the following summarises the status at the time of publication (autumn 2008):

1. The Green Machines. Here, the aim is to create machines that reduce environmental impact through their entire life-cycles. This entails measures such as the use of recycled materials for machine elements (targeted at 50 % or more), reduction of operating energy consumption by at least 25 %, introduction of zero waste production, complete dismantling and recycling of end-of-life machines, and the adoption of non-polluting alternative processes.

The team is developing eco-efficient process optimisation methods based on the modelling of manufacturing processes and evaluation of the real environmental consequences of all life-cycle phases. In particular, a new software tool (GREEM) addresses the use phase, which is the main contributor to eco-impact.

A series of hardware demonstrators is also in the process of realisation. Among these is a minimum quantity lubricant (MQL) system that will dramatically reduce the liquid waste from grinding machines. Abrasive processes consume more energy than cutting processes, so cooling liquid flows can reach several hundred litres per minute. MQL will cut the volume of waste by up to 95 % and bring power saving of up to 50 %.

Another improvement in this area is the application of electro-discharge dressing to extend the wear life of metallic bonded grinding wheels on a grinding machine.

Improved filtration performance for an environment-friendly wire electrical discharge machine (WEDM) again slashes the consumables budget by more than 50 %, while other process improvements are enhancing machining efficiency.

2. The User-centric Autonomous Machine. The objective is to achieve advances in usability and autonomy, with production machines that help and support the operator in all tasks. Avenues of research include built-in applications facilities, enhanced ergonomics, reduced maintenance requirements and improved operational aspects. Intelligent modules and knowledge databases will automatically recognise manufacturing tasks and adapt process conditions accordingly, leading to greater versatility, increased productivity and higher levels of user satisfaction.

An eco-efficient five-axis machine for friction stir welding (FSW) processes.

The main results are being embodied in demonstrator milling and gun drilling machines manufactured by three of the industrial partners.

3. The Manufacturing Breakthrough. New processes promising major improvements in performance are under investigation. The intention is to obtain a two- to five-fold rise in productivity, as well as an improvement in accuracy of up to an order of magnitude, compared with currently available machines and processes.

In this case four demonstrators are envisaged, illustrating self-calibration, predictive maintenance, versatile configuration, and improved control of accuracy and acceleration at high operating speeds. A three-axis high-speed milling machine from Fidia (Italy) is the subject of life-cycle analysis for eight different manufacturing solutions.

4. New Business Paradigm for Machinery. To create added value for production machinery manufacturers, this track is performing economic research to determine new ways by which the industrial partners, and eventually the sector at large, can commercialise the results of the project. It is considering the creation of start-up companies and the definition of new ways of doing business – for example by selling production hours instead of machines. The new business models proposed

DANOBAT minimum quantity lubricant demonstrator system integrated in a machining centre for grinding.

will be investigated in order to be stand-alone results and, in principle, might be applicable not only to the results of the project but also to other specific products of the machine builders.

A software tool based on the life cycle analysis approach now permits assessment of the economical and environmental benefits of adopting a more innovative business model. It provides for quantitative analysis of the impact of using unconventional financial models and new forms of cooperation between suppliers and customers/business partners.

5. New Contents for Training, Marketing and Dissemination around Production Equipment. New marketing strategies and training courses are under development, both to communicate the results of the research work done in the NEXT project and to improve public perception of the production industry and its associated research. Socio-economic studies are being carried out to assess the impact of the knowledge and technologies generated, including the analysis of factors that influence exploitation – e.g. standardisation, ethical aspects and gender issues.

Stimulating new concepts

NEXT is stimulating research into new machine concepts, and improving the sustainability of manufacturing activities in Europe in terms of competitiveness, employment and environment. An important part of its contribution to employment creation lies in developing machines that are easier to use and less demanding for the operators, and in designing methods of training dedicated specifically to machine tools.

Today, the worldwide machine tool market is worth €35-45 billion/ year, of which American and Asian producers together hold a share of around 50 %. The NEXT generation machines have the potential to cut manufacturing costs by up to 40 %, increase productivity by 200 % or more, and boost up-time to 95-99 %. Their introduction in only a proportion of the user industries could propel European machine-makers towards an increasingly dominant global position.

NEXT • Next generation production systems
Total cost | **€21 745 801**
EC contribution | **€13 999 999**
Project duration | **September 2005-August 2009 (48 months)**
Coordinator | **Dr. Rikardo Bueno – FATRONIK-Tecnalia, Spain**
More information | **http://next.fatronik.com**

SMEs join forces in micro-machining innovation

An IP for SMEs, LAUNCH-MICRO is pioneering a range of technologies and tools that will equip Europe's small-scale machining enterprises with the means to compete in tomorrow's booming markets for miniaturised devices and components.

A probe head senses the 3D position of precision balls mounted on a calibrated ball beam, simultaneously measuring machine axis positioning and straightness with µm-level accuracy.

The miniaturisation of components is a continuing trend in the telecommunications, healthcare, biochemistry, automotive and other industries. Micro-injection moulding is seen as the most promising method for economical mass manufacture to the tight tolerances demanded for these ever-smaller devices. But adapting to the production of moulds with the necessary sub-micrometre features requires new technologies that are beyond the reach of many SMEs.

Micro-machining companies of the future will also have to offer the flexibility, speed and cost-effectiveness to respond to market expectations of shorter product life-cycles and increasing customisation. LAUNCH-MICRO, with 28 partners from six European countries, provides the scale and expertise to meet these challenges. Co-led by Spanish SME SORALUCE and the IDEKO research centre, the participants include 20 SMEs, along with four universities and four research institutes.

Range of techniques

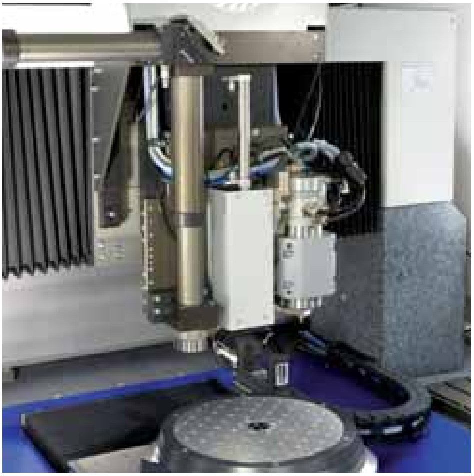
The partners are addressing four different fabrication techniques: micro-milling, micro-laser ablation, micro-wire electrical discharge machining (WEDM) and a combination of micro-sinking EDM with electrochemical machining (ECM). Their research is based on an initial survey of the requirements of the SME tool makers and end-user members of the consortium, together with the definition by the RTD institutes of the scientific and technological issues to be confronted.

Rather than down-scaling the existing technologies and know-how of the SMEs, the intention is to develop completely new concepts in machines, components, fixturing, measuring, control and verification, supported by simulation and modelling. Novel manufacturing strategies, man-machine interfaces and process optimisation routes are also being explored. Preparation of a series of demonstrators and pilot applications is underway.

A five-axis laser machining system uses ultra-short laser pulses for high-resolution production of complex 3D geometries in most solid materials. The non-contact process produces structure sizes down to the submicron level, with minimal thermal and mechanical damage. Applications range from the drilling of integrated circuit boards and semiconductor substrates to the cutting or repairing of lithography masks, manufacture of printing heads and fuel injectors, and generation of tribological structures on hardened metal surfaces.

In contrast to low-speed micromilling, the direct ablative laser process employs low pulse energy with high repetition rates and repeated traversing of the machining path. It requires motion axes with high acceleration, speed and mechanical stiffness, as well as high dynamic stiffness of the motor drive and accuracy of the motion path. In addition, the machine structure must provide mechanical and thermal stability, and good vibration attenuation.

KUGLER MicroGantry-machine in a configuration with three linear axes on air bearings and a C-axis rotary table, for micromachining of 2½D geometries by means of micromilling and picosecond laser processing.

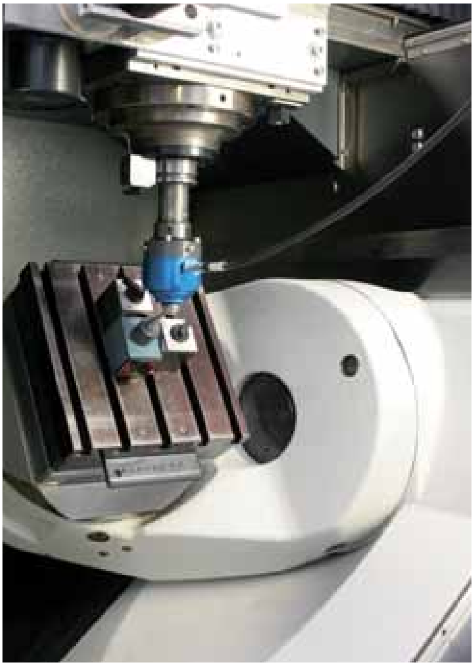


The modular design of the LAUNCH-MICRO machine will permit configuration for three, four or five motion axes, enabling users to keep starting costs low while permitting them to upgrade and adapt their systems to meet developing demands. It can be optimised for pure micromilling, pure ultra-short pulse laser processing, or a combination of the two technologies in one machine platform and CNC-system.

An improved picosecond pulsed laser source has also been developed, able to remove a thin layer of some 10 nm from virtually any material surface. Up to one million pulses per second can be generated and appropriately overlapped to create the desired microstructure. This is coupled with a new computer-controlled positioning system and supported by enhanced machining strategies derived from laser ablation modelling results.

A high precision micro-milling machine has been modelled using finite element analysis and error budgeting techniques to minimise dynamic errors under any operating conditions. Advancing beyond the current state of the art, it incorporates an axis with totally non-contact levitation, ensuring perfect linearity and eliminating non-linear errors. The demonstrator will feature an aerostatic milling head, but a magnetic bearing head will also be tested after completion of the project.

WEDM is a spark erosion technique that allows the production of structures with sharp edges that are difficult machine by other mainstream processes. Already used in many industrial sectors, it has a promising future in the fabrication of miniature parts. The LAUNCH-MICRO prototype is a micro-WEDM system capable of operating with thin wire electrodes of 50-100 µm diameter, to cope with a wide range of application demands. Equipped with a newly designed generator, it produces a cut that is 100 % free from electrolyte corrosion and preserves surface smoothness to within 0.2 µm. The latest-generation six-axis computer numerical control will allow the manufacture of highly intricate and complex parts.



MT MT-Check R-test measurement used to determine to location of a rotary axis accurately.

In contrast to EDM, ECM is a relatively new technique with considerable scope for further R&D. The goal within this project is to combine the benefits of the two technologies in a machine able to grind electrodes down to 5 µm diameter, with an aspect ratio of up to 100. Novel features include an on-machine electrode measuring device with an accuracy of ±0.2 µm. A radio frequency device will control and calculate the energy of the sparks, while a power supply generator giving ultra-short pulses will improve control of the process.

Several devices already at the stage of readiness for commercial exploitation are described in a series of fact sheets on the project website.

Empowering SMEs

By introducing flexible and affordable micro-manufacturing technology, LAUNCH-MICRO will enable the SMEs to become more competitive against their currently more advanced non-European rivals. At the same time, the ready availability of micro-sized parts will encourage innovation in industrial end-users of bio-reactors, lab-on-chip devices, sensors, etc., bringing new market opportunities to the manufacturers of machines, moulds and specialised mouldings.

Transfer of the new knowledge and best practices is being achieved by SME training courses, workshops and round tables given by the research partners. The inclusion of national and international machine associations in the consortium also helps to optimise the wider impact of the project.

LAUNCH-MICRO • Microtechnologies for re-launching European machine manufacturing SMEs
Total cost | **€9 458 220**
EC contribution | **€5 101 857**
Project duration | **October 2005-September 2009 (48 months)**
Coordinator | **Joseba Pérez Bilbatua – IDEKO, Spain**
More information | **www.launch-micro.org/**

Lightweight machines save materials and energy

Around 80 % of the mass of a conventional machine tool is used to provide the rigidity required for accurate operation. By developing technologies that reduce weight without compromising performance, ECOFIT promises dramatic reductions in both materials use and energy consumption.

Innovative control platform developed by ISW-Stuttgart and FATRONIK-Tecnalia for the ECOFIT Demonstrator.

ECOFIT aims to reduce the weight of the structural components and motion units of machine tools by as much as 70 %, resulting in savings of around 30 % in the energy required for their operation. As Europe currently produces some 70 000 machines per year, with an average installed power of 30 kW, this could reduce demand by 630 megawatts if applied across the whole sector.

Mechatronics replace mass

The concept of this STREP is to develop what are described as 'lightweight elastic machines with controlled flexibility'. Such machines employ mechatronic stiffness, rather than relying on mechanical rigidity to obtain the necessary high accuracy. In combination with the mass reduction, they incorporate new eco-design methodologies, innovative robust controllers for the flexible mechanisms, optical servo devices and smart materials featuring distributed actuators and sensors to the flexible components.

This approach will be exploited by the industrial partners in a 10-member consortium that includes machine-tool builders, manufacturers of sensors and piezo-actuators, and developers of hardware/software solutions for motion control.

Demonstrators in place

Following full analysis of the design requirements and a study of emerging materials such as polymer concrete, which exhibit low density and high damping properties, a test bed (ETB-1) comprising two axes of a machine tool has been constructed for the validation of materials, sensors and mathematical models.

Development continues on active vibration elimination methods using dedicated sensors and actuators for the damping of externally induced vibration. Damping

Assembly by FATRONIK-Tecnalia of lightweight machine components for the ECOFIT eco-efficient machine demonstrator.

by means of piezoelectric PVDF-film strain sensors and stress actuators has been thoroughly investigated, while various other sensors, actuators and control algorithms have been studied and tested on-machine.

Extension of an existing real-time simulation environment with a variety of multi-body sub-models (addressing flexible machine structural components, guideways, feed drive dynamics, axis controllers and the motion trajectory generation of the numerical control system) allows simulation of a reference model in the machine controller. Based on these sub-models, a model of an eco-efficient machine was prepared, comprising input/output, drive control and mechanical functionalities.

In addition, a machine from Spanish partner Nicolas Correa, which will be the basis for the ECOFIT demonstrator, has been modelled by means of a finite element method (FEM), the dynamic behaviour of which has been calibrated via experimental analysis.

Boost for Europe

From the economic viewpoint, lower moving masses and the corresponding reduction in size and power of motion units will lead to a reduction in the cost of machine construction, transport and, above all, use. This will help to strengthen and maintain Europe's global market position. The results and applications of this work are also expected to have a great impact on the application of lightweight high-performance, machine tools in many manufacturing sectors.

ECOFIT • Eco-efficient machine tools by means of radical mass and energy needs reduction
Total cost | **€3 118 081**
EC contribution | **€1 799 939**
Project duration | **September 2005-December 2008 (40 months)**
Coordinator | **Dr. Juanjo Zulaika – FATRONIK-Tecnalia, Spain**
More information | **http://ecofit.fatronik.com/**

Machining technique opens new doors for ceramics

Outstanding durability and performance under harsh conditions make engineering ceramics ideal for many demanding industrial applications. The MONCERAT project has expanded their market potential with new developments in machining and materials.

Using W-EDM, complex ceramic components are made flexibly and with great accuracy from a simply shaped ZrO2-TiN block. Since no molds are needed, this allows Maxon Motors to decrease lead times and reduce costs for small series production, and to optimise early prototypes before going to mass production.

Applications for engineering ceramics are found in areas such as the automotive sector, machine tools, process engineering, healthcare and the environment – yet they remain largely unknown in many other fields.

Today, most ceramics are prepared by conventional powder metallurgy, with some 60 % of all components needing some form of post-sintering machining operation. However, current processing routes do not allow economical production of complex-shaped, high precision components in small series or as prototypes. Trends such as mass customisation and micro/nano manufacturing also fuel the need for new technologies.

Interactive development

In the Specific Targeted Research Project (STREP) MONCERAT, three academic institutions and six industrial companies from five European countries joined forces to explore the use of the electrical discharge machining (EDM) technique to fill the gap. This erosion process is able to machine hard ceramics with great accuracy, provided they exhibit a sufficiently high conductivity to permit the transmission of electrical charges via a dielectric fluid. Suitable candidate materials were not commercially available prior to the start of the two-year STREP initiative, so the consortium, headed by the Catholic University of Leuven, embarked on a parallel study of material formulations and production methods, processing technology and machine functionality.

Their collaboration covered all steps in component design and manufacturing (basic ceramic material production, optimal design, manufacturing and end-user applications), bringing important new insights into the relationships between material microstructure and EDM behaviour.

Breakthrough findings

Major breakthroughs were the development of new ceramic composites, including nanocomposites such as ZrO_2- WC, together with related EDM technology to machine them with excellent quality. The end-user partners have already evaluated the new materials in their own products, reporting significant improvements in functional properties such as wear- and corrosion-resistance, high-temperature resistance and strength-to-density ratios.

The project also showed that simple substitution of a classical component (e.g. steel) by a ceramic counterpart was not a successful strategy; adapted design was found to be essential to reach the optimal results. Making the latter point clear to various industries was an important aspect of the MONCERAT dissemination effort.

A substantial shift from classical materials to ceramic-based components is foreseen. Industry analysts estimate a global market growth for ceramics of around 5-7 % per year, reaching €1.5 billion in Europe and $2 billion in the USA by 2009.

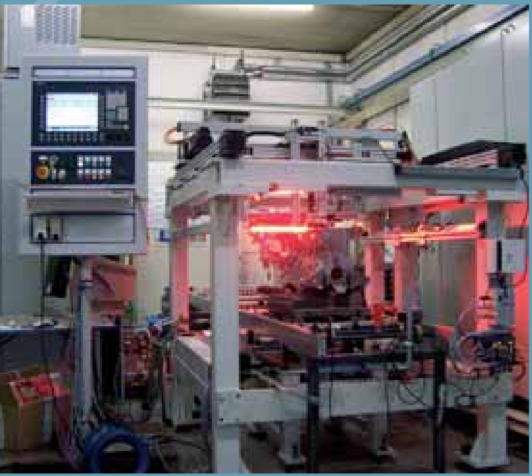
Manufacture of drawing dies in a new range of extremely hard and wear-resistant ceramics gives increased lifetimes.

A ceramic injection moulding tool is used to mass-produce small ceramic components. This example was made in boron carbide, one of the hardest materials on earth, to reduce mould wear.

MONCERAT • Broadening the application field of ceramic components by joint and interactive research on EDM machining technology, novel ceramic materials based on nano-powders made by SHS and design methodology
Total cost | **€4 011 627**
EC contribution | **€2 298 964**
Project duration | **January 2004-June 2007 (42 months)**
Coordinator | **Prof. Dr. Bert Lauwers – Katholieke Universteit Leuven, Belgium**
More information | **www.moncerat.org**

Trained machines make light of visual inspection

Visual inspection is an essential aspect of quality control for many kinds of manufactured goods. DYNAVIS is defining new ways to automate this process, by devising efficient and accurate human-machine learning procedures.



DYNAVIS inspection system during construction.

Virtually all companies that make products using automated production and assembly lines need some form of quality control, often including visual inspection. Automation of this task requires solutions to the problem of how to enable a machine vision system to mimic human 'accept/reject' decision-making. Usually, this is accomplished by software embedded in devices such as smart cameras.

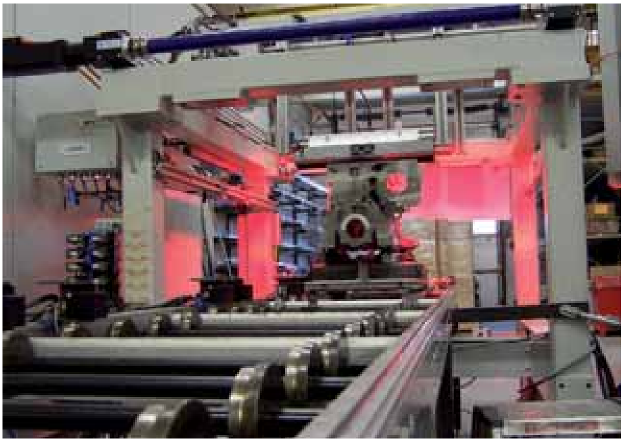
The process entails comparing the images of test objects with those of a perfect master image, detecting the differences and classifying the observed features as faults or pseudo-faults. In the past, training the machine for this purpose involved use of a preset and defined set of rules, in which individual parameters were set manually and adapted gradually to an expert inspector's decisions. It could require several months of iterative reprogramming and testing to achieve satisfactory results.

Dramatic time saving

The STREP initiative DYNAVIS will streamline this time-consuming task, replacing lengthy trial-and-error procedures with human-machine cooperation to teach even complicated inspection tasks. Short term interaction between an operator and the image-processing machine will allow systems to adjust dynamically to new products or changes in the production process without the need for extensive re-engineering. This will build the basis for a wide range of possible applications in quality control, robotics, scheduling processes, logistics, etc., where the appropriate reactions can best be learned from a human operator.

Under the coordination of Austrian research institute Profactor, eight partners representing four EU Member States are cooperating in this three-year programme. Together, they are applying advanced learning techniques and fuzzy logic theory to the development of a methodology whereby the machine can gradually build a hypothesis about which objects are 'good' and which are 'bad' for their intended purpose.

Instead of relying on lengthy manual adaptation, the software of the test system learns from the operator, who continues to perform manual inspections alongside those of the system for a period of time. Whenever system and operator disagree, the system adapts its decisions accordingly. Once this phase is completed, there is no further need for operator intervention; communication will then continue directly between the inspection system and the plant control system.


DYNAVIS inspection system.

Flexible and robust

The standard procedure of image segmentation, feature calculation and classification is employed but, whereas existing approaches usually train only a final classifier, DYNAVIS also considers fault detection and features as part of the trainable structure. This brings much greater flexibility and adaptivity.

As a first step, application-specific pre-processing is used to extract the relevant regions of interest in the image and describe them as a series of feature vectors. These vectors serve as input to a learning classifier, which enables the system to learn a set of rules provided by the operator.

The way that features are calculated is not always a simple matter. The size of an object may be the number of pixels above a certain threshold, it could also be the area inside the convex hull, or there might also be the option of joining two objects that are close together. In order to increase the flexibility, reduce the number of features needed and improve the robustness of the classification, feature calculation algorithms are tuned by adapting parameters such as thresholds, intervals in histogram calculations, or frequencies or directions for textural features. This is done in a supervised process that selects the parameters in a way that minimises the within-class scatter in relation to the between-class scatter. The specific choice of downstream classifier may also be considered in the optimisation process, to create decision boundaries that can easily be reproduced by the classifier.

Sequential analysis of each defect may not be enough for the overall evaluation of a test object. Often, the totality of defects – their spatial arrangement, number, total area, etc. – is important. Good/bad decisions are therefore usually made on the whole image, by aggregating the individual features. For example, an object could be deemed to be bad if there are at least five faults with diameter larger than 1.5 mm. More sophisticated decisions can also be made, for statistical or other purposes.

Human factors addressed

Another particular consideration is that there may be systematic differences in the verdicts of different operators, depending on their levels of skill and experience. For his reason the framework includes expert-specific classifiers. Each classifier is trained to reproduce the decisions of individual experts and, in order to achieve a unified final decision, the results of these expert-specific classifiers are combined. Trainable and fixed ensemble classifiers for on-line training have been developed, implemented and tested for this purpose.

Research is also being conducted into ways of predicting the success or failure of learning at an early stage of the training process. This has led to two different methods: curve fitting and a bias/variance prediction method. Both showed good results. Classification accuracies have now reached 93 %-98 %, and may further be improved with a shift of focus onto the early processing steps.

High accuracy

First prototypes tested in industrial environments have achieved very good results in terms of hits and robustness. For example, at the end of a learning phase with complex tasks involving 1 000 parts, 99.8 % good/bad decisions were hits even without prior fine-tuning of the application.

Two industrial demonstrators will eventually showcase the successful combination of machine vision and machine learning. First, an existing line for inspecting the printing on CDs and DVDs will be extended at the plant of industrial partner Sony, Austria. Secondly, a system for surface inspection of compressor parts at Atlas Copco, Belgium, will be built during the project, with a projected error rate of less than 1 %.

Hundreds to benefit

Broader dissemination and exploitation of the scientific and technological results is being undertaken by the European Association of Innovating SMEs (EurExcel). This could enable hundreds of small enterprises producing or using vision systems across Europe to benefit from the findings to improve their competitiveness.

DYNAVIS • Dynamically reconfigurable quality control for manufacturing and production processes using learning machine vision
Total cost | **€2 532 867**
EC contribution | **€1 712 000**
Project duration | **October 2005-September 2008 (36 months)**
Coordinator | **Dr. Christian Eitzinger – Profactor, Austria**
More information | **www.dynavis.org/**

No-die forming brings short-run economy

Traditional sheet metal forming processes are rapid and productive, but involve high initial investment that renders them impractical for short runs. The SCULPTOR project shows the viability of a versatile alternative technique that will be affordable for small batches and even prototyping.

In the SCULPTOR prototype, two opposed tools allow incremental forming of sheet metal parts with no dedicated die. One tool acts as the forming device, while the other provides support. These roles can be interchanged in order to combine convex shapes with concave cavities in the same component.

Sectors such as the automotive and aeronautics industries use forming processes – notably stamping and deep drawing – to produce complex-shaped components in a great variety of sheet materials. These traditional methods are based on the use of large presses and costly application-specific dies. Their main advantages are speed and high productivity, but the high initial equipment cost and the need for specific dies for each piece makes them inflexible and unattainable for SMEs. Furthermore, the fine-tuning of a new product typically entails expensive and time-consuming trial-and-error adjustment.

Forming is thus uneconomical for small batches – e.g. spare parts, designer furniture and panels for trains or special vehicles – which represent an annual business volume of more than €4 billion.

Consequently, there is international demand for a more flexible and affordable manufacturing technology, able to produce complex and larger sheet metal components with high reproducibility and accuracy on intelligent automated machines.

Promising process

The solution proposed in the SCULPTOR project is based on a technique known as 'incremental sheet forming' (ISF). This entails the gradual plastic deformation of a metal sheet by the action of a spherical forming tool, the trajectory of which is numerically controlled. It allows complex shapes to be achieved using simplified supporting dies, and can be carried out on either a standard CNC milling machine or a robot.

Initial investment costs are only around 5-10 % those of a stamping process, as precise dedicated dies are not required. The process is also reasonably flexible, since different shapes can be produced on the same machine, simply by adapting CAD programs and optimising tool strategies. To date, however, industrial penetration has been impeded by a lack of speed and accuracy; difficulties with cracking, wrinkling or thinning of the parts; and inadequacies in process control.

A physical limitation was the fact that reproduction of the targeted shape is only successful if the deformation of the sheet is purely plastic, which is often not the case. In practice, the sheet frequently exhibits elastic spring-back when the tool retracts, leading to significant deviations from the desired geometry, particularly for complex components.

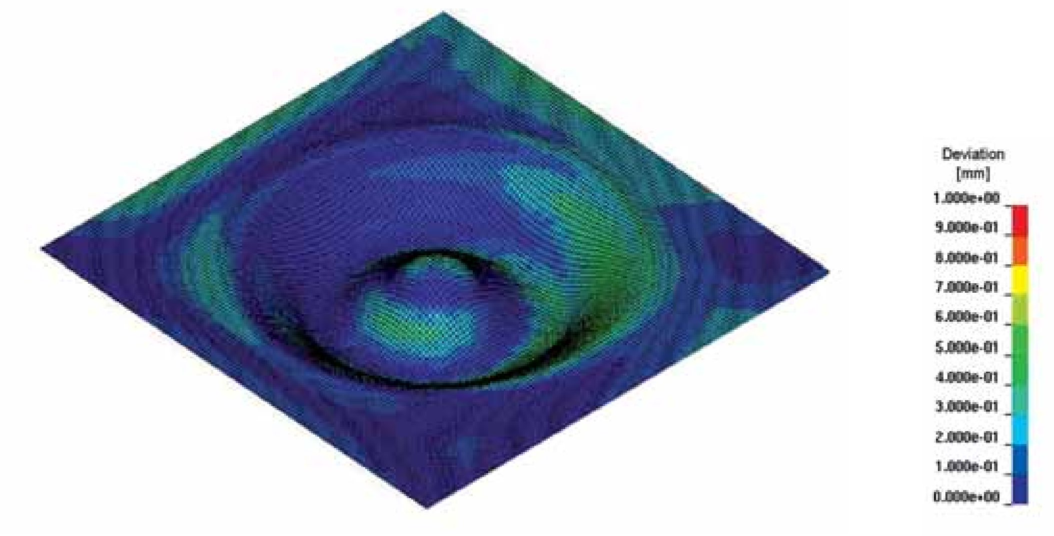
New concept

The SCULPTOR partners, coordinated by FATRONIK-Tecnalia, Spain, set out to solve these problems and acquire deeper knowledge of the underlying phenomena. As well as exploring improvements to the conventional ISF process, they introduced a new concept (described as the SCULPTOR process) in which the usual set-up is replaced by a pair of opposing generic forming tools operating in tandem against the two sides of the blank sheet.

With tool trajectories numerically controlled in terms of position, force, speed and orientation, more complex and larger parts can now be shaped in shorter processing times. Flexibility is also enhanced, since there is no longer any need for even a simple supporting die.

Working on the two process variants in parallel involved multidisciplinary research in several critical domains:

- development of smart materials based on integrated sensors with suitable properties to allow both ISF and SCULPTOR to be self-controlled;
- adaptation of numerical models to characterise the processes and predict the behaviour of blanks during forming;
- process optimisation, via adequate intermediate stage surfaces, strategies for tool paths, parameter definition, selection and placement of tools, etc.;
- realisation of intelligent and integrated monitoring and control systems based on use of the smart materials and sensors in forming tools, blanks and blank-holders.



This FE model has been developed in order to better understand and optimise the SCULPTOR process.

Milestones achieved

Two SCULPTOR prototypes have been developed and are already running. One has been integrated in a horizontal milling centre and the other in a triceps robot. In the case of the milling machine, an extra axis in the tool direction ensures that the second tool remains in contact with the sheet throughout the process, thus acting as a real incremental die system that supports the forming effect of the first tool. A smart tool has also been integrated into a prototype, allowing measurement of the forces acting upon it, as well as of the resultant sheet thickness.

Two computer models have been implemented and validated. A quick one-step version is able to predict sheet thinning during the process, which is a necessary input for the second, full-scale model. The latter proved to give reasonable predictions of both forming forces and strains in the sheet, and was further improved by measuring the friction coefficient between tool and sheet.

Among notable outcomes of the extensive programme of experimental work are specific tools for ISF of titanium sheets, and optimised forming strategies for box-shaped geometries.

Prospects for change

The development of ISF for industrial applications will lead to more innovative designs and new business opportunities for European enterprises. It is expected that the new technology, with its lower direct and indirect production costs, will replace traditional processes in the mid-term for short and medium-sized batches and for rapid prototyping applications. In the longer term, it will pave the way for more fundamental changes in manufacturing.

Shorter development cycles and a potential reduction in product time-to-market of up to 70 % will help to increase the competitiveness of European sheet metal companies, as will the ease and convenience of part modification, and the elimination of productivity losses due to tooling deterioration.

A 75 % decrease in maintenance costs and avoidance of the need to store bulky dies are yet more reasons to consider the replacement of expensive hot and cold forming processes that are unable to meet the cost and quality criteria for smaller-scale production.

SCULPTOR • Sustainable and smart shaping process for radical innovation in European metal forming manufacturing
Total cost | **€3 094 777**
EC contribution | **€1 793 507**
Project duration | **August 2005-July 2008 (36 months)**
Coordinator | **Asun Rivero – FATRONIK-Tecnalia, Spain**
More information | **http://sculptor.fatronik.com/**

Drive must continue

Each of the projects described in this brochure is contributing to the common objective of building a healthy and sustainable manufacturing sector in Europe, not only in terms of local production of goods, but also as a global supplier of knowledge-based tools and services that the rest of the world cannot match.

Despite the external challenges from nations such as China, Korea and India, the EU continues to supply much of the equipment for the factories that fuel their growth. Internal challenges also exist, but these can be overcome with strategies and initiatives for transforming European industry into an activity competing on the basis of high added value, rather than lowest cost. To drive this change it is necessary to take appropriate and timely action to intensify new product and process R&D, aggressively pursue productivity improvements, rediscover the value of service and attract the right people.

Because of the demand for customised products with short delivery times, business must shift from designing and selling physical products to supplying a system of products and services that are jointly capable of fulfilling users' demands, while also reducing total life-cycle costs and environmental impacts.

The machining industrial sector should base its industrial transformation in the future on its capacity to propose, through a holistic approach in the global market, high added value products and services in which the product is not the machine tool itself, but a capacity of production.

Research would be needed in five core fields that determine manufacturing excellence:

- technologies beyond borders – delivering high performance, high quality and optimal cost;
- digital and virtual engineering – to simulate processes, logistics, etc., in order to be faster than others;
- intelligent manufacturing systems for flexibility and rapid product change;
- sustainable manufacturing including eco-societal design of product/services and production processes;
- organisation methods and systems – new business models, control systems, life cycle management and high-value services.

NEXT and the other projects in the machining cluster are active in all of these areas, implementing and building according to the roadmap proposed by the Manu*future* ETP. It is essential that this momentum be maintained, or ideally increased, to support the goals of the revised Lisbon strategy for growth and jobs. As well as continuing to focus on the transnational integration of research into the core technologies of manufacturing, it is equally vital to address the transformation of the business environment, attract more young scientists and engineers to the sector and create a favourable climate for entrepreneurship and innovation among European enterprises.

European Commission

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J.L. Vallés, Head of Unit RTD-G2 'New generation of products'

Manufacturing is at the base of the European economy and quality of life. Many sectors of manufacturing, such as production machinery, have a leading position in the world. Moreover, machine tools are at the core of an enormous range of production processes in many sectors of manufacturing industry including automotive, aerospace and transport. Today, there is a pressing need to introduce new technologies in order to meet changing societal demands and stay ahead of global competition. New and user-friendly production technologies, and their incorporation into the factory of the future, are currently being developed in several research projects in Europe. This publication presents in a condensed form the objectives and main achievements of six selected projects under the 6th Framework Programme in the field of machinery and production equipment. Their results will contribute to the manufacturing systems of the European factories of the future.

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