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Knowledge-based mechanical and manufacturing engineering: the Basque Country experience

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1. Introduction

The Basque Country is a highly industrial region in the north of Spain, with an economy based on manufacturing for automotive, aeronautics and machine construction, where some technological research agencies and universities work in innovation. These are the main partners of a new approach for research and innovation, working together with the Basque industries. In this manner, a knowledge cluster about new manufacturing technologies is consolidated.

This article presents a dual model for collaborative and cooperative research and development of advanced manufacturing systems. On one side is the development of new knowledge about manufacturing process and machine tools, performed under a collaborative approach known as CIC marGUNE (High Performance Manufacturing Cooperative Research Centre), which activity is developed in the Basque Country. On the other side the new knowledge resulted from the R+D projects is rapidly transfer to new technicians and engineers through the Unit of Machine tools, placed in the School of Engineers of Bilbao. In this way research and formation are simultaneously performed with a maximum profit for industry.

This work describes the CIC mission, proposed paradigms, structure and modus operandi, and mentions the projects carried out to date. An overall assessment of results so far is also given. Otherwise, the Machine-Tool Unit of the Faculty of Engineering of Bilbao (UPV/EHU) arose as a co-ordinated initiative from both companies in the machine-tool sector and public institutions (Basque Government and Provincial Council of Bizkaia) to foster specialised training of higher technicians, the execution of research projects, and diffusion of activities towards other sectors of society. This Unit makes possible a rapid transfer of CIC marGUNE results to basic formation, and to industry by means of the “fresh” new engineers to be inserted in Basque companies. This experience could be useful for other regions of the size, population and industrial economy similar to the Basque Country.

2. The Basque Country collaborative research and formation

Country-wide investment in R&D of industrial manufacturing ranges from more than 2.5% of GDP in Sweden, USA, Denmark and Germany, to intermediate levels of between 1.5 and 2.5% in France, Norway, and U.K. and lower levels in the Czech Republic, Ireland, Italy, Spain, Portugal and Greece. Spending level in the Basque Country is slightly higher than that of Italy, but lags behind that of other countries with a similar per-capita income, as population of the Basque Country is 2.6 millions.

Entrepreneurial players in the field of industrial technology must make more effort to develop research programs in strategic areas that can benefit the economic and social development of the country in the medium and long term (Santero & Gopalakrishnan, 2000). If this objective is to be attained, more attention must be paid to the culture of collaboration and networking of entrepreneurial research centres in order to find solutions to specific needs in areas where collaboration is considered necessary due to the volume of demand, its strategic nature or increased likelihood of providing a localized industrial production.

Industrial products made in the Basque Autonomous Community are of medium level in terms of technology, criteria by (Hatzichronoglou, 1997), so the risk of becoming less competitive if technology does not progress fast enough is high. Ways must be found to exploit knowledge and assess the results. Any delay between new knowledge generation and final application must be avoided. Collaboration between universities, technological centres and companies is highly required to compete with emerging countries and economies.

There are success stories in collaborative research work between different players in the chain of science (Chiesa & Toletti 2004), technology and industrial entrepreneurship which can be used as models for many other countries. Other examples are the CRCs in Australia, which are the result of a government program established in 1990 that has seen the creation of 158 centres of this type (Australian Government, 2005). Other longstanding examples include more than 100 associations in Germany (Albers et al., 2007), Kplus and Kind/Knet in Austria, RRITs in France and Competition Centres in Sweden (Table 1). In a similar way to the Basque Country, the Spanish government in 2007 has set up new projects for strategic national consortia on research and technology which will entail collaborative research. However the main difference between Spanish and Basque approach is that in the Basque collaboration scheme a new office is funded for each thematic area, for a) coordination and b) performing of some part of common research. The common office budget is derived from public sources and private ones.

On the other hand, ensuring proper orientation of common alliance of research and action requires a continual technological monitoring of databases on scientific articles and patents (van Dulken, 1999), and of trade affairs such as those about machine tools like EMO and Euroblech in Hannover, JIMTOFF in Japan and IMTS in Chicago, and national fairs such as Metav in Germany, BieMH in Spain, Bimu in Italy and application based fairs such as Euromold in Frankfurt (Moulds and dies), Le Bourget Fair in Paris (aeronautics), K fair of Düsseldorf (plastics). Universities have an easy access to scientific databases and to the main scientific journals, in addition to the increase in the Open Access journals, such as Sciyo (www.sciyo.com).

Acronym	*Country/region*
CIC Biogune	Basque Country (Biotechnology)
CIC Microgune	Basque Country (Microtechnology)
CIC Biomagune	Basque Country (Bio materials)
European Research Association for Sheet Metal Working (EFB)	Germany
Cooperative Research Association for Mechanical Engineering (FKF)	Germany
Kplus	Austria
Competence Centres	Sweden
Cooperative Research Centres (CRC)	Australia

Table 1. Collaborative research in the word some examples

On the other hand, the 110 year old Faculty of Engineering of Bilbao (ETSI) is one of the oldest faculties of the University of the Basque Country (UPV/EHU) and the second eldest of Spanish Faculties of Engineers. Throughout its long life, the engineers trained in thus school have collaborated decisively in industrial research and progress, comprising a group of valued qualified professionals, as demonstrated by the extraordinary employment indices achieved (96% in 2008). Today, the faculty has over 3,500 students enrolled and over 350 professors. The Faculty is a university centre whose purpose is engineering training and research, optimising resources available to meet the changing needs of society based on maximum quality criteria.

In this context, the Engineer qualification has a long tradition at the Bilbao ETSI. Due to the versatility of the Industrial Engineer's training not only does he/she have the classic option of entering an industrial company, but often their professional career leads to other destinations such as Technological Centres, Public Administration, etc. However, one of the fields with more professional outlets for graduates is undoubtedly the solid metal-mechanical industry fabric of the Basque Country, and in particular the Machine-Tool Industry and Manufacturing Technologies.

The manufacturing engineer is usually responsible for the product, involving not only the solution to problems which inevitably appear throughout the manufacturing process, but also in the development and improvement of production methods, including tools and machinery. Other areas under manufacturing are quality control and production personnel management, whereas the plant engineer is responsible for the installations necessary for the production process.

2.1 Changes required in engineer's formation

European universities are undergoing thorough restructuring. The Bologna Process have a decisive impact on both future graduates and labour markets to which they are orientated, thus it is worth reviewing some of the contents with greatest impact, likewise that regarding the insertion of new graduates in the industrial sector. At present, the advances in the plan application are highly important following the London Communique guidelines (London 2007).

The interest in developing skills in educational programmes corresponds to education being essentially focussed on the student and his/her capacity to learn. And in exchange he/she is expected to show a greater actor with high levels of responsibility and commitment. For example, below are the skills employers most value in graduates: a) capacity to analyse and synthesise, b) capacity to learn, c) capacity to solve problems, d)capacity to put knowledge into practice, e) capacity to adapt to new situations, f) concern for quality, g) information management skills and finally h) capacity to work alone and in a team.

Relations with industrial companies are revealed as a worrying fact in reports related to the Spanish university. According to 2005 data only 15% of Spanish companies turned to universities for the execution of R+D projects, moreover, according to 2004 data from the National Institute of Statistics only 0.9% of companies saw universities as an appropriate partner for innovation. In general, this fact is repeated on the Basque Country, and must be solved with specific actions as those presented in this chapter.

Faced with this new situation, the Unit of Machine Tools (of the University of the Basque Country) arose as an instrument to maintain the university at the forefront of engineers' training for the mechanical manufacturing sector. This activity comes under research and teaching related to manufacturing processes, including high speed milling, electro-erosion, processes based essentially on laser and grinding. Use of CAD/CAM and computer based techniques are also part of the work carried out. The group has a workshop equipped to perform machining tests, with state-of-the-art technology machinery likewise instrumentation and monitoring systems enabling maximum information to be obtained, such as: magnitudes, forces and temperatures generated in the process among others.

The Technical Director, professors and organizers of the Unit are at the same time part of the CIC marGUNE, a collaborative research centre (CIC) devoted to developing new manufacturing technologies, explained in the following Section. The Unit is going to solve one of the drawbacks of innovation systems in the last 15 years in the Basque Country, the lag between research and formation of new technicians and engineers: new knowledge and basic formation are in this way joint under the same scope.

3. CIC marGUNE

The CIC marGUNE is a collaborative research centre (CIC) focused on new manufacturing technologies, a platform for multi-industry collaboration with a view of developing capacity in strategic economic and social areas for the Basque Country in the medium and long term development. However, its framework of action is not merely regional but must extend to national and European levels.

The purpose of CICs is to optimize scientific and technological capacity and generate new ranges of industrial design end products with help of entrepreneurial research in the Basque Country. There is therefore a need to generate entrepreneurial capacity with other industrial players in the system, undertaking to develop a common strategy for progress in a specific field of industrial science and technology within the fields of strategic research defined by the government under its Science and Technology Policy.

One of the areas where CIC marGUNE (www.margune.org) has most potential is in bringing together research characteristic of universities, with approaches more closely linked to actual industrial practice and characteristic of technology centres, with help of existing industrial corporations.

The organizational structure of CIC marGUNE is based on a CIC Core (a little office) and Virtual partners (the universities, technological agents and companies involved in research projects), seeking maximum flexibility. The virtual team comprises the researchers working on each project, who are provided by the various technological members (universities and technology centres) of marGUNE according to needs for each action. The number of researchers working on the activities of marGUNE can therefore vary from one year to the next without the system suffering as a result.

Clearly, research work is concentrated in the hands of the virtual team of the CIC, but this does not mean that it is impossible to form new research teams in new areas not covered by the technological members and to integrate them into the CIC Core of marGUNE. Basically, the function of the CIC Core is to handle a small part of the actual research work, to coordinate activities and to take responsibility for ensuring that the results are transferred and exploited.

Number of active members of CIC marGUNE (Virtual partners) has grown steadily since its founding. Membership now includes representatives of the leading industrial players at the different levels of the value chain in manufacturing technologies:

- Universities: University of the Basque Country (Faculty of Engineering of Bilbao and Faculty of Donostia), Faculty of Engineering of the University of Mondragon (MGEP) and the Faculty of Engineering of the University of Navarra (Tecnun).

- Research centres: Ideko S. Coop., Fatronik, Labein, Tekniker, Koniker S. Coop., Aotek S. Coop. , Euve, Lortek and Azterlan.

- Industrial corporations: Danobat Group S. Coop., Goratu SA, CIE Automotive SA, ITP SA, SAPA SA, Etxe-tar, Loire Safe, Grupo Alfa, Ona Electroerosion SA, CAF SA, Spanish Machine-tool Association (AFM) and Mondragon Industrial Automation.

- Intermediate innovation organizations: Foundation Invema. The participation of intermediate innovation organizations allows that results will be properly transferred to the fabric of Industry in the Basque Country. In this way INVEMA works very close to machine tool manufacturers.

The roles of each partner in marGUNE are somewhat different, but technological centres and universities are in charge of that research with more risk and long term objectives. Specific R+D projects are developed under an strategic plan, making use of personal and facilities of universities, technological centres and companies.

However there is one of the partners with a special dual role, the University of the Basque Country in which the Unit of Machine Tools and Manufacturing technologies (hereinafter, the Unit) is placed and currently running, with 20-25 students each year. By means of this Unit, new knowledge develop by marGUNE is rapidly transferred to new technicians and finally to Basque companies. The University of the Basque Country is public, so no big commercial purposes are derived from their basic research activities.

The most important committee of marGUNE is the so-called Projects Directory, in which all partners carry out their new project proposals, and make regularly the tracking and evaluation (partial and final) of the just developed research projects. Decisions from this group are evaluated by the General Board and the Industrial Partners Board. Additionally an International Scientific Committee gives some recommendations and help to aim the main scientific goals for research projects.

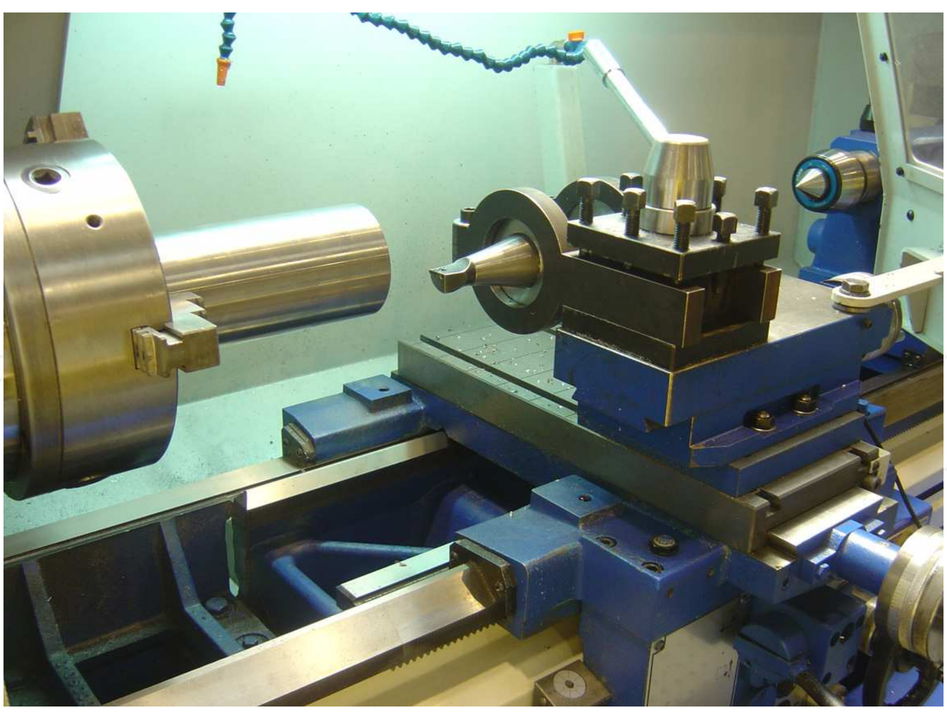

Fig. 1. Experimental set-up for ultrasonic assisted turning, developed in marGUNE

3.1 marGUNE R+D projects

The CIC marGUNE is developing research projects since 2001, but a systematic management of projects is applied since 2003. To the initial topics about material removal technologies, new manufacturing techniques were incorporated. Today all mechanical manufacturing technologies are in the scope of the CIC. Three research programmes were performed in the last ten years:

<u>2003-2005 phase</u>

These projects entail 3 million euros of investment, aiming at the following issues:

- Machining process monitoring. In the last machine tool fairs some machines with complex monitoring systems have been presented. This effort tries to improve this technology in the Basque machines.

- New machining processes assisted by heating addition systems. This technology is increasing in demand, being known as Rapid Tooling, Rapid Prototyping, or Rapid Manufacturing.

- Advanced measurement systems applied to experimental studies of machining processes, focused in developing good models for machining processes. Effort in this line has been important, with models for milling, drilling and turning using Finite Elements Technology and semi-empirical approaches. The development of virtual manufacturing is a common topic in technology trends and modelling a tool to improve the performance of machining operations.

- New ultrasonic based machining processes, for drilling, turning and stress relaxation. A complete start of the art and several applications were tested to be able to know the potential application of ultrasonics to machining (see Figure 1).

<u>2005-2007 phase</u>

These projects entail 3 million euros of investment, being developed with multidisciplinary groups:

- Study of material deposition processes based on mixed technologies, using laser as main heat source.

- Measurement of tensile stress and structural changes due to the machining process applied. The integrity of the machined surface is frequently one of outputs to be evaluated. Surface integrity is a term that involves several considerations: surface finish, elimination of cracks, no chemical changes, no evidence of thermal damage and adverse residual stress.

- Assessment of integrity and accuracy during machining processes, using modelling techniques based on finite elements.

- Advanced machining process from the point of view of process modelling, virtual simulation and monitoring. A full scheme where modelling and monitoring is applied to milling was developed.

- New forming process to generate low rigidity new generation car parts.

- Analysis of drilling, turning and dressing grinding wheel processes assisted by ultrasonic systems.

2008-2010 phase

These projects entail 4,5 million euros, including technologies of material removal, sheet forming and bending, laser applied to polishing and material deposition, and a new line of iron casting was included. Work was divided in branches related with the final production objectives:

- Manufacturing without defects, achieving high precision. Work about titanium and nickel alloys was an intense topic in this objective.

- Manufacturing without waste, in dry or near-to-dry conditions.

- Manufacturing in high performance conditions, of difficult-to-cut materials, composites, special iron castings, etc. In this line, machining of the new gamma TiAl alloys was developed.

This organisation aimed at final objectives was not clear for a quick management of the projects, so marGUNE is getting back to projects focused on basic technologies.

3.2 R+D projects and basic formation

Results of research projects were transferred to Basque companies by means of specific actions and making use of some financial support from the Basque and Spanish governments. But a lack of engineers with capacity to lead the new projects was detected by companies and intermediate associations. Based on this statement, the Unit of Machine Tools and Manufacturing Technologies of the School of Engineering of Bilbao started in 2008, with the mission to perform a special formation about new manufacturing technologies, becoming a great instrument for a rapid spread of marGUNE research results and other projects in the field of manufacturing. This Unit completes the range of formation oriented to technicians in the Basque country, acting in coordination with other technicians' formation centres and companies.

4. The Unit of machine tools and manufacturing technologies

The Unit offers a special course to the 5th-year students of the a) Manufacturing Intensification, b) Mechanical Design and c) Automatism and Systems Engineering. Therefore the real objective is to make a very intense formation on technology matters before students finish their basic formation, orientating their future competences to the manufacturing sector.

The course is divided into 2 clearly differentiated parts, each responding to the student acquiring a series of different skills. This structure combines a first semester where a series of theoretical seminars are imparted with practical application to real problems in several manufacturing sectors; and during the second semester the student undertakes an Industrial Project under an Apprenticeship Scheme (remunerated training). Student training is completed with direct contributions from leading companies in the sector in the form of: conferences, talks, visits on real industrial plants. To pass the course, students are required to obtain 21 (210 hours) credits minimum of the 30 (300 hours) offered, which are grouped in the following modules:

- Module 1: Advanced Machine-Tool Design (I): Structural and material concepts; machine precision; machine spatial, kinematics and dynamic of mechanisms; parallel kinematics in machine-tools.

- Module 2: Advanced Machine-tool Design (II): Vibrations in complex systems. Modal correlation; machine-tool precision and advanced function control; machine-tool mechanical elements; machine-tool engines and regulators; machine-tool verification and calibration; magnitude measuring and sensors.

- Module 3: The Machine-tool and the Process (I): High performance machining; abrasive processes; CAM and virtual manufacturing.

- Module 4: The Machine-tool and the Process (II): Non-conventional machining processes; laser and emerging processes; machine-tool dynamic behaviour: vibrations during process; surface integrity of machined products.

- Module 5: Machine-tool Control: Numerical control: architecture and programming; basic automation and PLC's; pneumatics and hydraulics applied to machine-tools.

- Module 6: Machine-tool life cycle and its processes: ICT's applied to machine-tooling; 3D design and drawing; life cycle, LCA analysis and conceptual design.

- Module 7: Machine-tool Innovation: Methodological research; R+D management and technological surveillance; project development.

Regarding training in companies this is done via an Apprenticeship regime already in force and of proven efficacy in the Bilbao ETSI. The differential factor is to get the student into machine-tool, automotive, aeronautical of precision companies, working in innovation projects, so they can use some of the knowledge acquired during the training seminars to the company developing. Student must describe an innovative solution for a company problem making use of the knowledge obtained from the Unit seminars.

Each student is subjected to special follow-up and support by the Unit teaching staff. As the students are from different specialities and qualifications an additional effort is required from the teaching staff to adapt contents and nomenclature used.

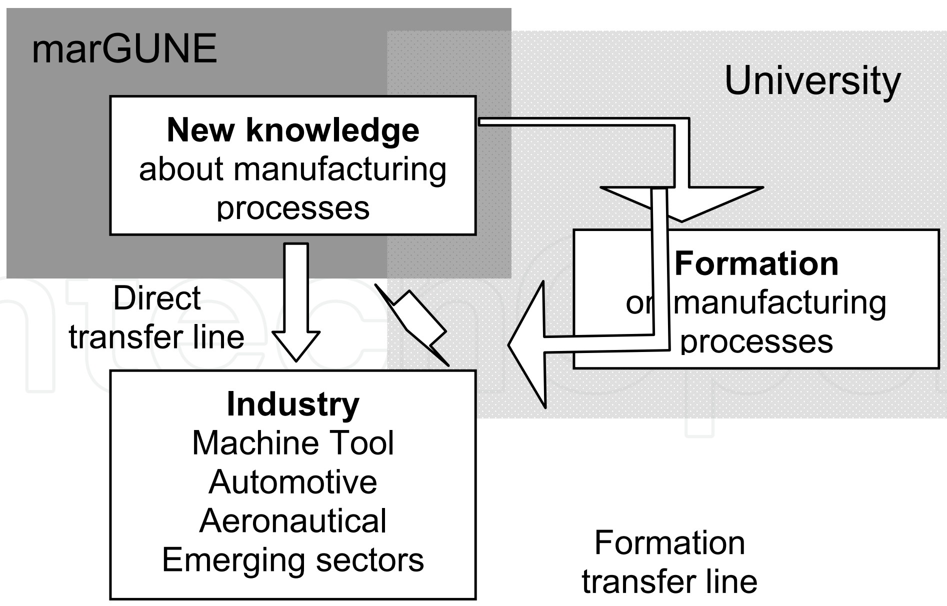

Fig. 2. Manufacturing research: transferring results to industry

5. Transference of research results to the industry

There are two main keys for a successfully transfer of knowledge both from the university to industry and from research structures to university, as shown in Fig. 2. In this manner, the university is the necessary link between the new knowledge and the direct application of it. At the same time the own university is a research agent collaborating in research projects, some of them into marGUNE scope. In Figure 2 are shown:

- The *direct transferring* of manufacturing research projects from marGUNE to industry, or directly by the own university itself. If this line is successfully completed, companies will use results to improve the performing of their processes. However it is a common matter of fact that methodologies and basic and deep know-how is retained in the technological agents.

- The *formation transfer line*, where research results are included in the regular formation lectures of future engineers, in the University of the Basque Country is mainly done by the Unit of Machine Tools. In this case not only results but basic methodologies and criteria for innovation are given to industries by means of the new engineers.

5.1 Development of new knowledge and inclusion in basic formation

The University of the Basque Country is member of the CIC marGUNE, as explained above. Therefore new results obtained in the marGUNE context are continuously impregnating the seminars of the new editions, shown in Figure 2 as the *formation transfer line*. Some examples of matters derived from CIC projects included in the basic training programs are the following:

- New technologies about *material deposition by plasma and laser* (Lamikiz et al., 2007), are now a 12 hours seminar in the Machine Tool Unit (in Module 4), with a special training in laser use. Students know about the laser applications for repairing blades, tool dies, moulds, etc. The laser becomes a "tool" for them with a lot of possible applications.

- *Machining assisted processes* are explained by a 10 hours seminar (in Module 3), in which the ultrasonics assisted processes and the high-pressure assisted turning are presented to students. In the same line *Thermal Enhanced Machining* processes are described, with a deep discussion of the possible applications to industry.

- Controls of kinematic platforms with serial or parallel chain are developed by students using digital control (Module 2). Two prototypes are able for the testing of algorithms developed by students after a 12 hours seminar.

- Machining of titanium and nickel alloys using high speed milling or electrodischarge machining is the topic of a special seminar open to technicians recently graduated. It is included in the Module 3.

Fig. 3. a) Students learning the five-axis machining technology. b) Component made by five-axis milling

- Five-axis milling (see Fig. 3) in the mould manufacturing, for extrahard tempered steels (Lacalle et al., 2007). Students received a 20 hours seminar about CAM, after a 20 hours seminar devoted to CAD with solids.

- Grinding at high speed for automotive components, modelling the thermal and mechanical effect of grinding wheels on parts.

- The use of long twist drills to remove big amount of material, achieving high homogenous components with high strength, as shown in Fig. 4. This knowledge is now applied to build monolithic parts for aerospace applications.

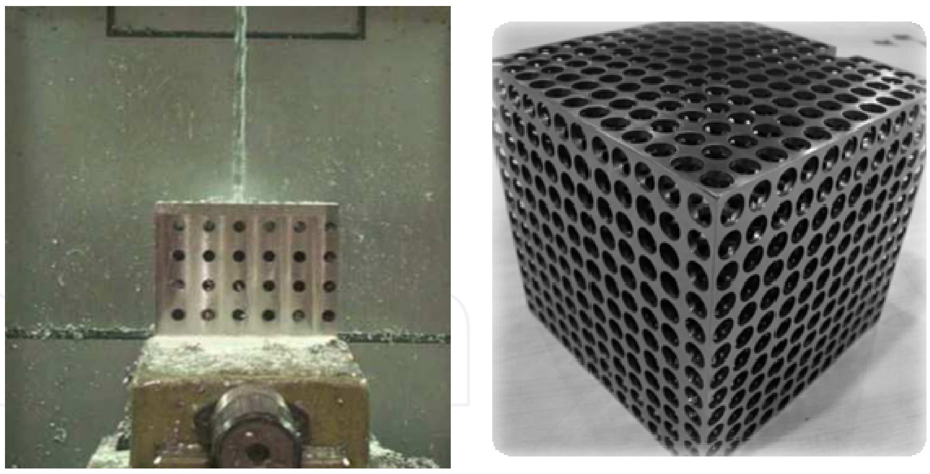

Fig. 4. Using twist deep drilling as a roughing technique: a) Drilling of a cube. b) Cube after drilling all the faces.

5.2 Transfer from university to industry

The main way to trespass the new knowledge from marGUNE to industry by means of the Unit of Machine Tools is the practical work doing by Unit students in the training period, in which they must applied the know-how received in the seminars but to real industrial cases. This is the second step in the *formation transfer line* (Fig. 2). A few of the projects currently in progress are the following:

- Implementation of a 3D design system for machine tool changers. The student is carrying out several prototypes of how a 3D system can facilitate development of new tool magazines, working in an SME devoted to the construction of this accessory.

- Advanced machining of superalloys. Optimisation of machining processes on nickel and titanium alloys, using new cutting tools is the main topic to perform.

- Active vibration absorber. The student is developing the software of a vibration absorber applicable to milling, to eliminate the phenomenon known as regenerative chatter.

- Design of special machines for automotive components. Two students are now in the technical office of a company oriented to transfer machines and multispindle lathes.

- Five-axis milling of complex surfaces, focused on blades and spherical-type forms. Two student work in a SME technical office implementing a CAD/CAM for complex parts.

6. Conclusion

The University is obliged to offer quality studies, which likes meets labour market demand. The Unit of Machine Tools came about in this context and as a result of the joint work between institutions, industry and the university in Bilbao, as an initiative aimed at training graduates in the engineering branch pursuant to the specific needs of the Basque Machine-Tool sector and Manufacturing Technologies.

Thus the Unit is the appropriate framework for an approximation of the university to industrial fabric demands, satisfying the functions of training graduates; and is likewise a stable framework for the execution of research projects and catalyser for transference of results to companies. This is a real fact when marGUNE projects are finished (Lacalle & Lamikiz, 2008) and knowledge is spread to society and industry by means of new engineer's formation.

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