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HardPrecision

PROJECT N° : 01785

ACRONYM : HardPrecision

TITLE : Simultaneous five-axis hard milling for highest precision

PROJECT CO-ORDINATOR : Hemtech BV, NL

PARTNERS : **Hemtech Machine Tools BV, NL**
Walter Dittel GmbH, D
Module Works GmbH, D
Cemecon AG, D
Norma BV, NL
Moldit SA, P
Tallers Fiestas, E
System 3R International AB, S
Jabro BV, NL
Hirschvogel GmbH, D

RTD Performer : **Fraunhofer IPT, D**
Czech Technical University, CZ

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1 Project execution

1.1 Project objectives

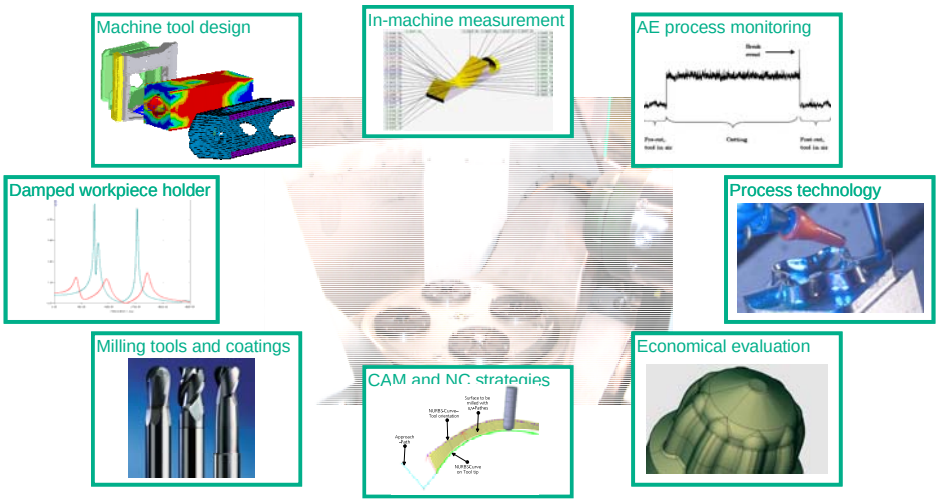
European tool and die making SMEs are facing a steady loss of competitiveness in their markets, since existing manufacturing technologies cannot fulfil the increasing demands on part quality. These companies are eagerly seeking for new technologies to enhance the economic production of high-quality tools and dies.

The project HardPrecision aims at developing a five-axis hard milling process for highest precision. The technology will be able to produce high-quality products in considerably less total throughput times. The five axis hard milling process has to be understood as a highly complex process chain being influenced by many factors – starting with CAM and NC technology, the machine tool, tool and coating technology up to process and monitoring technologies and the final evaluation by in-machine measurement.

The project encompasses the optimisation of a milling machine by applying light-weight parts and the enhancement of milling technology for high-hard materials. The investigations are concentrated on conventional and powder metallurgical high speed steels and the usage of coated solid carbide tools. These materials are typically used in tools for cold forging or injection moulding of highly abrasive materials. Moreover, a part measurement system capable of quality control within the machine tool is developed.

Main work packages are:

- development of a light-weight carbon-fibre spindle box and integration into the milling machine
- development of a in machine measurement strategies
- optimisation of a damped clamping device
- development of a process monitoring system based on Acoustic Emission signals
- enhancement of cutting tool accuracy and development of optimised tool geometries
- qualification of novel PVD coatings
- adaptation of CAD/CAM/NC process-chain and development of specialised tool path strategies
- machining technology optimisation for five axis hard milling



HardPrecision - Bringing together the process chain of high precision hard milling

Besides contributing to an improvement of the bonds between Member States and Candidate Countries and to an considerable increase the competitiveness of the participating SMEs the project will encompass scientific, technical and societal objectives, which can be summarised as follows:

- better scientific and technological knowledge about milling of high-quality surfaces on hard-ened materials
- lifetime enhancement of tools and dies, contributing to further knowledge and productivity of the EU-industry
- drastic reduction of hazardous substances in the production of tools and dies significantly improving environmental and health conditions in Europe.

1.2 Involved contractors

In the following the companies of the project consortium and their tasks are described.

B.V. Hemtech Machine Tools, The Netherlands SME co-ordinator
The Hemtech Company is developing a high-precision five-axis hard milling machine for mainly the die & mould industry for extreme high accuracy parts. Hemtech is a sister company of the Hembrug company, in Haarlem now in Europe as leader in the field of high-precision hard turning lathes for extreme high accuracy parts.
Hemtech's main tasks in the project are the project co-ordination, the optimisation of the milling machine prototype and the technical development of additional components for the milling machine as well as

the evaluation of the relevant demonstration of hard steel parts beyond 60 HRC.

Walter Dittel GmbH Luftfahrtgerätebau, GermanySME participant
Walter Dittel GmbH Luftfahrtgerätebau develops and manufactures high-performance systems for process monitoring and the automatic balancing of grinding disks. Dittel supports its customers with technological innovation and precision, efficiently combining a comprehensive understanding of the production process with solid know-how in sensor technology and process monitoring.
In this project the Walter Dittel GmbH will enlarge the specialised know-how by transferring the acoustic-emission monitoring system upon the hard milling process. Therefore, the company will adapt consisting systems or develop new concepts by means of specific requirements from the hard milling process.

ModuleWorks GmbH, Germany SME participant
The company deals with software development in the areas of CAD/CAM and CNC technologies. The main business of ModuleWorks is implementing 3, 4 and 5 axis tool path creation algorithms and according post processors to drive CNC machine tools.
ModuleWorks will participate in the project by creating 5 axis roughing and finishing strategies for hard milling The post processors of ModuleWorks are implemented using object oriented programming techniques and are very fast in terms of transforming part related tool paths to machine specific output.

CemeCon AG, Germany SME participant
The CemeCon AG is world-wide technology leader in the range of hard- and super hard coatings. With its coating service, the company offers a comprehensive spectrum for the coating of tools and components.
The development and adaptation of coating technologies to the special needs defined by higher accuracy and increasing workpiece hardness is the task for CemeCon within the proposed project. An intense co-operating with Jabro as cutting tool supplier and Fraunhofer IPT as RTD-performer for process technology guarantees highly sophisticated and applicable solutions.

System 3R International AB, Sweden Other enterprise
System 3R is a global group which covers the business fields development, design, production and marketing of methods, handling equipment and tooling systems for the engineering industry.
The main task of System 3R within this project is the development of a new damped workpiece clamping device for the amendment of tool life

and surface quality, based on latest developments of the company and its adaptation to the optimised hard milling machine

JabroTools B.V., The Netherlands **Other enterprise**

Jabro Tools is a manufacturer of high precision end mills made from solid carbide materials. The tools are used for tailored applications in the die and mold, automotive, aerospace and medical industry. It is today owned by the Swedish tool manufacturer Seco Tools and therefore no SME. Jabro's main contribution to the project will be the development of more sophisticated milling tools in terms of accuracy and highly adapted to the hard milling process.

Research Center of Manufacturing Technology RCMT, Czech Republic **RTD-performer**

The goal of the RCMT is to build up a highly professional and well equipped educational and training facility as a research base for the Czech machine tool industry and for the Czech mechanical engineering as a whole. Another important objective is to study foreign experience and new prospective technologies of the near future and to generate innovative solutions.
Main tasks of RCMT within the project are the design and implementation of the novel in-machine part measurement device for quality control as well as the improvement of the machine tool prototype.

Fraunhofer IPT (Germany) **RTD performer**

The Fraunhofer IPT has the mission to conduct application-oriented research and development. The structure of the Fraunhofer IPT offers solutions to highly specific problems as well as problems that require integrated system-wide solutions. This is done by combining interdisciplinary contributions from the fields of process technology, machine and control components, metrology, quality management, technology planning and organisation.
Two departments are contributing to the achievements within the HardPrecision project. The department production machines deals with the optimisation of the machine prototype and the design of the novel carbon-fibre z-axis spindle box. The department process technology mainly works in the investigation for process optimisation and development.

End Users **SME / Other**

The companies Norma BV (The Netherlands), Tallers Fiestas SA (Spain), Moldit SA (Portugal) and Hirschvogel Umformtechnik GmbH (Germany) are taking part in the project as End Users of the technology.

Their main tasks in the project are the supply of information on actual parts, quality and time requirements as well as the definition and manufacturing of milling specimens for the HardPrecision technology.

1.3 Performed work

The work within the HardPrecision project has been divided into 7 major work packages:

Work package N°	Work package title	Lead contractor Short Name
1	Definition of specifications	Norma
2	Characterisation and optimisation of simultaneous five axis milling machine	IPT-machine
3	Development of additional equipment	RCMT
4	Further Development of Cutting Tool and Coating Technology	Jabro
5	Adaptation and optimisation of the CAD/CAM-process chain	Mod
6	Machining process optimisation	IPT process
7	Verification, economical and technical evaluation of the HardPrecision technology	HIVO

Work package list of HardPrecision

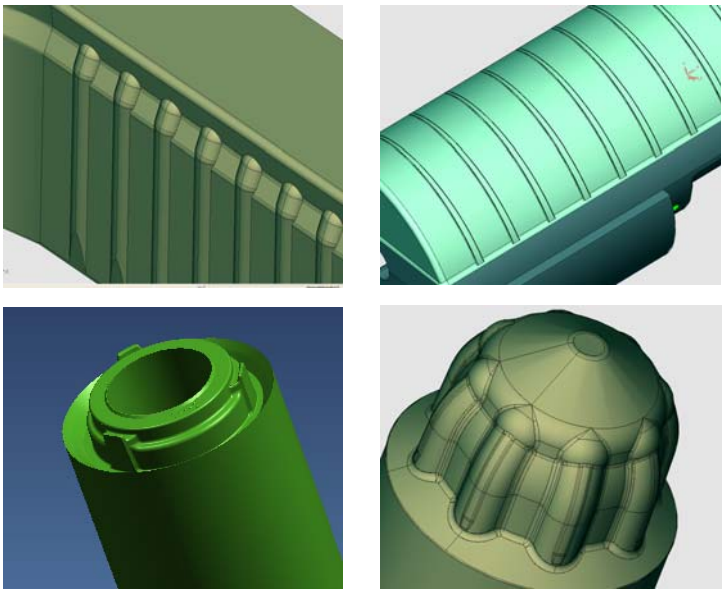
Within these work packages, developments were foreseen in order to improve the holistic system of high precision hard milling – taking into account that a successful further development of this technology can only be achieved when all relevant tasks along the process chain are being included into the developments and ameliorations.

After the project, it can be said that the initial project idea of "bringing together the complete process chain of hard milling" in terms of knowledge, capacities and partners was a successful approach which has enlarged the total knowledge of this process for all partners. The main work was performed at the RTD partners Fraunhofer IPT (Germany) and

RCMT (Czech republic) regarding the holistic development of machine tool components and the hard milling process technology.

In the following, a short overview of the performed work shall be given – focussing on the developments which were addressed in the single work packages. Results are described in the next paragraph.

WP1 – Definition of specifications
A questionnaire was defined and filled out by the HardPrecision project partners in order to define the needs that have to be fulfilled by all the developments foreseen in the project. Based on the results of this questionnaire, a technical meeting took place where sample parts were defined for the validation of the technology at the end of the project. Each of the end users of the developments defined a typical part which reflects a challenge for the hard milling technology.



Tab. 1: Geometries of the HardPrecision sample parts

The defined parts reflected a high challenge for the milling technology and cannot all be completely machined in the hardened stage. For each part, the actual process chain was defined in order to compare the developments made in the projects with the state-of-the-art.

Based on the overall definition of targets for the whole HardPrecision project, the detailed procedure and targets for each work package were defined in different technical meetings.

WP2 – Characterisation and optimisation of simultaneous five axis milling machine

The project was based on a five axis, fully hydrostatic milling machine prototype which was provided by the project partner Hemtech. During the whole project, all developments were adapted to this prototype while the prototype itself was ameliorated in terms of precision and functionality incorporating the results and findings of the different work packages. Characterisation and measurement of the machine tool included an indirect machine characterisation with the manufacturing of special test geometries and an analysis of the outcomes. Additionally, direct machine characterisations were performed measuring the properties of every single axis as well as of the whole structure in order to implement suitable corrections.

The main work performed in work package 2 was in terms of development of a fibre reinforced spindle box which shall reduce the weight of this structural machine part which is subjected to fast movements in the machining process. A high requirement in position accuracy leads to a stiff and often massive design whereas high accelerations require a lightweight construction. Even the design of metal machine parts inhibit a low thermal dilatation and a high structural damping. In order to meet the requirements of high stiffness, low mass, low thermal dilatation and high structural damping, fibre reinforced plastics enable stiff and lightweight constructions. E. g. carbon fibre reinforced plastics en-able a young's modulus respective to the fibre orientation up to 400kN/mm² at a mass below 2g/cm³. Regarding furthermore the narrow design space, especially of the spindle box, only these carbon fibre reinforced plastics were able to fulfil the design requirements.

The developments of the spindle box incorporate a material characterisation phase where especially thermal and chemical resistance of suitable materials was tested. After this, a topology optimisation of the spindle box structure was performed. Focus of this work was the design of an optimal structure of the spindle box concerning mechanical and thermal stability. The topology optimization calculates an optimal structure, e.g. material distribution, of a part base on maximum allowable design space. This method is based on the Finite Element Method and is typically applied to parts that require a minimum mass, yet high stiffness, such as machine tool components. Topology optimization can only handle isotropic materials, thus no direct optimization of fibre reinforced

components is possible. Therefore, a virtual isotropic material was defined with the average properties of the fibre reinforced material which was be used in this project. Based on the results of the topology optimization, a design model of the structural components was developed, taking into account the requirements concerning the ability of manufacturing from the fibres and plastics kind of view and economical reason.
Finally, a spindle box was manufactured apron the design of the spindle box on the Fraunhofer IPT shop floor wherefore the production processes for the solution had to be developed.

WP3 – Development of additional equipment
In work package 3, several developments for an amelioration of the hard milling process and adjacent technologies were bundled.

Development of in-machine measurement device
First of all, the RCMT worked on the development and analysis of an optimised strategy for in-machine measurement (IMM).

The task of the IMM has been solved in the RCMT within the 2006 and 2007 years. During the 2006 period of the HARDPRECISION project, RCMT studied all known and established classic methods and experience, known from the CMM – Coordinate Measuring Machine practice. Some problems had to be analyzed: During the measuring procedure on CMM, the work piece is located in certain stationary space position and all the X, Y and Z measuring movements are performed by the measuring probe. Unfortunately, only very few machine tools can satisfy this requirement and the work piece usually moves during measurement at least in one of the X, Y or Z axis. The situation on the Hemtech five-axis milling machine prototype (NanoFocus) is still more complicated because the touch probe moves in the Z and Y axes whereas the work piece moves along the X axis and makes additional rotary and tilting movements. First tests on the type LM-1 and LM-2 milling machines were performed after their reconstruction for highest sensibility of movements and optimization of CNC controls.

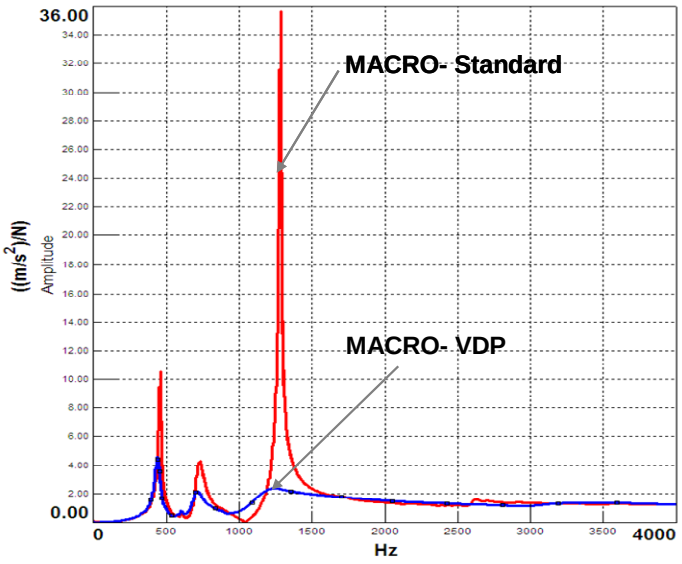
In April 2007, the IMM system has been successfully installed on the Nano-Focus machine in IPT Aachen. Simultaneously, new software for measuring of multidirectional accuracy and sensitivity of touch probes, developed in the RCMT was tested on the Nano-Focus machine.

Different systems were tested in order to compare 3 axis, 3+2 axis and 5 axis measurement procedures. The developments were tested and evaluated when measuring two of the described sample work pieces at the milling machine. This was successfully made including the computer simulation of measuring cycles. This made it possible to generate

measuring NC programs for both work pieces and to show the machine on the EUROMOLD exhibition including the simulation and performance of IMM measuring cycles using different measurement systems.

Development of damped clamping device

The damped clamping device is based on an exclusive development of the System 3R company enabling a high damping close to the engagement area of the cutting tool and thereby enhancing process stability by significantly reducing vibrations or shatter that may occur. In the HardPrecision project, this system was further ameliorated in order to adapt it to the special needs of the hard milling process and to integrate it into the hydrostatic milling machine environment. Besides the integration concept into the milling machine prototype, further tests regarding the damping behaviour were performed which showed a significant improvement of the damping behaviour when certain design rules are being applied to the system. As an example, the following figure shows the comparison in damping behaviour of a conventional work piece holding chuck and the novel development "VDP".



Dynamic tests on undamped and damped clamping system

Development of acoustic emission system

The aim of this task was the development of an acoustic emission system for characterisation of the hard milling process. During the project, measurements were made in order to find out about the abilities of such a system in terms of analysing tool breakage or even tool wear during the process. It was found out that the hard milling process has to be analysed

on the basis of a much faster and more accurate system than those available today.

Based on these investigations, the project partner Dittel started to set up a novel hardware for acoustic emission measurement and analysis. A prototype of this system has been tested during the project and will be further detailed and brought to a market product by Dittel after the project.

WP4 – Further Development of Cutting Tool and Coating Technology

The cutting technology is the major technological factor when hard milling is regarded. It was decided in the project to focus on solid carbide tools which are being coated with PVD coatings for highest thermal and mechanical stability. In finishing operations, cutting tool accuracy has a mayor influence on the achievable results. It serves as linkage between machine and part and therefore was looked at with special interest. By investigating optimised grinding techniques and enhanced machine tool accuracy, tools with a considerably increased precision were developed at Jabro Tools. Additionally, novel milling tool geometries were regarded in the project and brought to implementation in a close interaction with work packages 5 and 6 as their performance can only be increased when the application on complex work pieces can be guaranteed.

Increasing work piece hardness leads to highest requirements regarding the coating technology. It has to fulfil several, even contradictory requirements due to extreme stress and temperature load at the cutting edge. Therefore, tests were performed to improve coating technology in terms of highest abrasion and heat resistance as well as thermal insulation. The coatings were developed and deposited at Cemecon and tested at the Fraunhofer IPT.

WP5 – Adaptation and optimisation of the CAD/CAM-process chain

To reach optimum machining conditions in hard milling, CAM-strategies were developed for five-axis milling. In roughing, optimisation was mainly performed to reach high material removal rates considering the limitations of spindle and tool technology investigated in work package 4. In combination with the conventional prefinishing, strategies were developed to reach a constant allowance on the surfaces in a short time. Especially the manufacturing of some of the sample parts has proved the large advantages of this approach in terms of tool load and manufacturing time.

Finishing operations were looked at in order to achieve overall surface quality better than 0.3 µm Ra. Therefore, smooth and accurate movements have to be assured considering the dynamics and kinematics of the machine axes. This was achieved by a solution directly using CAD-faces for the generation of tool paths without interpolation. Especially in five-axis milling, bad positioning of axes can lead to intolerable engagement situations which are strongly lowering part accuracy and surface tolerance. Within this task, finishing strategies were especially focussed at to ensure optimum engagement situations, a constant width and depth of cut and predictably high surface quality and part accuracy.

Additionally, this task also comprised the optimum linkage of CAM and NC to the machine control in terms of post processor development and the direct consideration of the machine kinematic and dynamic abilities with the NCProfiler software available at Fraunhofer IPT.

WP6 – Machining process optimisation

In the project, four tool steel grades have been identified which were investigated in detail, being at a hardness between 57 and 65 HRC. The conventional 1.2379 and HS6-5-2 were compared with the powder metallurgical materials S790 and K390 of the Boehler company. Detailed investigations were performed in order to analyse the machining mechanisms of such different materials and to find optimum machining conditions for the hard milling process under different conditions.

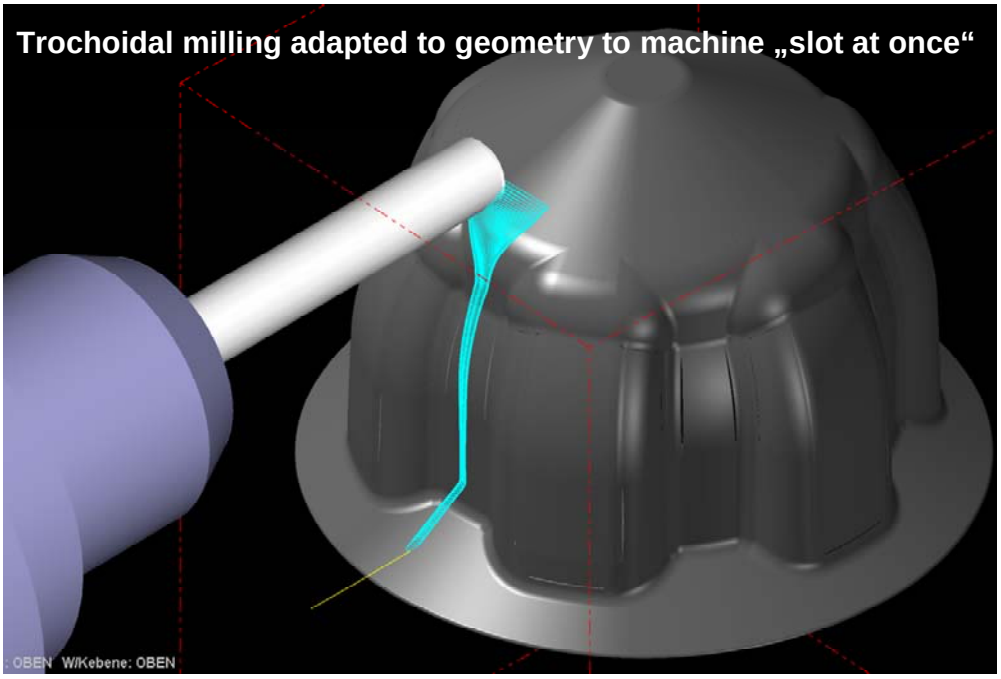
An optimisation of machining parameters such as spindle revolution, depth and width of cut, feed rate and cutting speed was performed based on existing knowledge on sides of the end users and the Fraunhofer IPT and the materials and geometries defined in work package 1. This task especially focused on best use of the new possibilities created by the optimised machine prototype and its ability of widening process limits known from previous projects. The influence of the developed damped clamping device on the process was investigated. For this purpose, test runs on conventional and the prototype machine were performed during and after the development of the damped chuck. Measurements of tool wear, contouring accuracy and surface quality were done, evaluating the novel device and deducing room for improvement.

WP7 – Verification, economical and technical evaluation of the HardPrecision technology

For the evaluation of the project, it was decided to manufacture four demonstrator parts – one being proposed by each of the end users in the project: Hirschvogel, Norma, Moldit and Tallers Fiestas.

The work at the end users facilities and the Fraunhofer IPT took place in a close cooperation also with the other project partners. It revealed many issues where project developments aided at solving the manufacturing tasks, but also such where further developments will be needed in order to achieve the final target. In the following, some major challenges and results are described for two exemplary parts.

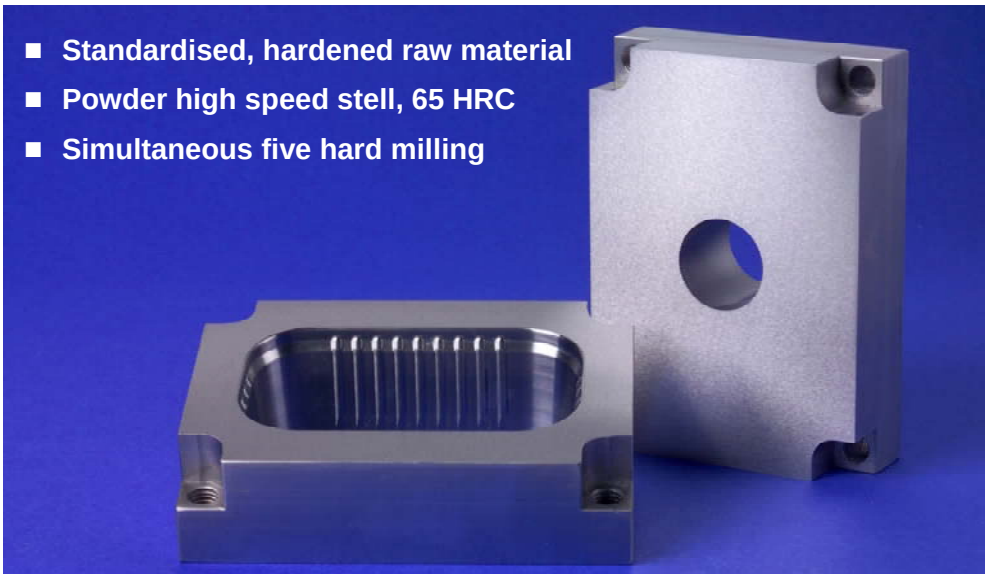
Looking at the Hirschvogel sample part, one of the major challenges was the rough machining process which had to be shifted from soft machining to a machining process in the hardened state . The following figure shows the trochoidal milling process which was applied in order to pre-machine the slots at the sides of the part. This process largely shortened the manufacturing time in comparison to a conventional hard roughing process and enabled a good surface approach in this step.



Trochoidal rough milling of the slots

Looking at the Norma part, the main advantage of the novel approach is the shortened process chain in terms of substituting time-consuming process steps. Regarding the product spectrum of the chosen part, this is

of special interest as the parts which are being produced have a high variety. With the novel approach, it is possible to start with pre-machined and hardened material which is then machined in a one-step approach towards the final shape. Lead time can be extremely reduced in such an approach even when the total manufacturing time is only reduced by a small factor.



Standardisation and hard milling to reduce the lead time

1.4 Results of the project

The major achievements of the project have to be splitted into two major areas. On the one hand, the development of the machine tool itself and the additional equipment – mainly concentrated within work packages 2 and 3 – have shown very good progress with a direct impact for the involved partners in this area. These are mainly machine and component manufacturers which benefit in terms of new products and services they can now offer in this area, mainly incorporating:

- The milling machine tool of Hemtech which is now at a status of market-entry showing a real step beyond the state-of-the-art. This is mainly due to the full hydrostatic concept which has not been realised previously in a five-axis milling machine delivering highest precision and vibration damping which is an excellent basis for hard milling of difficult to machine materials

- The fibre-reinforced spindle box being developed by IPT is at a status of finalised prototype and will be integrated into the next generation of the milling machine tool. It showed an excellent behaviour in terms of stiffness and significantly reduces the weight of this structure. As it is subject to highly dynamic load during the milling process, this will significantly enhance the machine tools capabilities.

- The in-machine measurement device regarded by RCMT where the concept of such a system could be proven even for high precision applications. It is of vital importance for end users to know about the capabilities of such a system when measurements between process steps have to be performed without additional clamping effort.

- The damped clamping device of System 3R which is capable of enhancing the process stability and performance in hard milling applications was adapted to the milling machine tool. This system is at market-ready stage and will be applied in this and other machine tools in the future.

- The acoustic emission measurement and characterisation of the hard milling process proved to be extremely difficult also in comparison to the grinding process where it is already applied successfully in practise. The project nevertheless largely contributed to a detailed and profound definition of specifications which has led to the development of a completely new analysis unit by Dittel which is actually at a prototype status. The partner Dittel expects to finalise this system and will then be able to offer an analysis unit also for hard milling processes mainly based on the results achieved in this project.

On the other hand, the process technology side was a major subject of the project – where developments were made with special interest for the end users and in close interaction with the other partners.

- Milling tools and coatings play a major role in the hard milling process. Jabro Tools and Cemecon were involved in this task working on high precision tools as well as on an enhancement of the coating performance. Especially the hot temperature abrasion resistance was enhanced leading to better results in the high speed milling process. New tool concepts were developed together with the process and CAM experts which are especially adapted to five axis hard milling.

- The CAM process including the NC code generation and its transfer and quality on the milling machine control have to integrate many other developments and "transfer" them into a knowledge based programming environment. Major achievements reached by

ModuleWorks in this field comprise the implementation of the special "barrel" tool geometry into a CAM environment with full collision checking as well as the precision and surface quality enhancement by analysing and optimising the complete process chain.

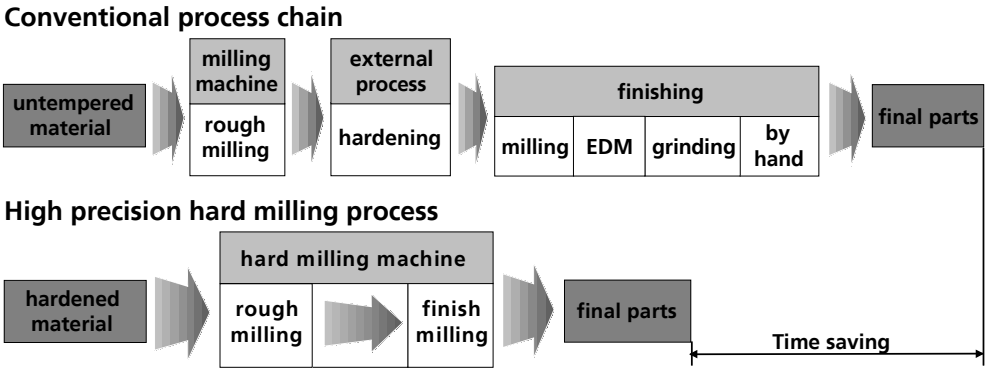
- All developments were tested and evaluated by producing real parts which were initially defined in cooperation between IPT and the End Users of the technology – Hirschvogel, Norma, Moldit and Tallers Fiestas.

It can be said that the initial project idea of "bringing together the complete process chain of hard milling" in terms of knowledge, capacities and partners was a successful approach which has enlarged the total knowledge of this process for all partners. The dissemination of results has reached a large audience being present in many journals and conferences during the entire period and especially by being present with the machine tool and the developments at the Euromold fair 2007 in Frankfurt which is the by far most important fair for the tool and die making branch worldwide.

1.5 Impact on the competitiveness of European SMEs

The growing loss of competitiveness of the European tool and die industry (where the End Users of the HardPrecision project are belonging to) can only be reversed by substantially reducing lead times and enhancing part quality simultaneously. This was the major basis for the introduction of the HardPrecision project.

The basic idea can be seen in the following figure: the substitution of time-consuming finishing operations of the conventional process chain (EDM, grinding) with the much more productive hard milling process is a key issue. Additionally, the hard milling technology is capable of substantially reducing or even eliminating manual finishing operations, eliminating idle times with unclamping, re-clamping and set-up operations. In a complete five axis hard milling process chain, the parts can be machined on one only machine tool, not on many machines as it is the case in the conventional process chain.



Reduction of lead times by means of the high-precision hard milling process.

The case studies in the project have shown that products can be machined in app. 15-30% less machining time in comparison to the conventional process chain. But when costs and effort for logistics are considered, the novel technology has an even higher advantage. This is due to the fact that the total number of manufacturing technologies and places (for instance, machines) can be significantly reduced, automation becomes much easier. The so important lead time reduction is significantly easier with such a process approach. This represents a huge increase of their productivity and provide them with a substantial lead over their overseas competitors.
Regarding precision hard milling machines, the most sophisticated solutions nowadays are produced in Japan. However, the know-how for single machine and tool components is mainly owned by divers' suppliers from Europe. The Dutch SME Hemtech, for instance, possesses the expertise in producing wear-free hydrostatic bearings and combining them with high-resolution measuring systems in order to achieve an excellent positioning accuracy of the machine axes better than 0.1 µm. Therefore, Hemtech has now qualified its fully hydrostatically guided machine concept for hard milling in the framework of this project.
After performing a careful market analysis of the tool and die industry, Hemtech identified a growing market for **high-precision** hard milling machines. On basis of this analysis, Hemtech expects until 2010 a steady sales increase rate of 4 machines per year after the end of the project. This will enable Hemtech to produce up to 20 high-precision hard milling machines in 2012 and to provide at least 15 new jobs for European workers. Since the companies System 3R, Dittel, ModuleWorks, Jabro and Cemecon are now producing different systems for the Hemtech milling machines, or producing cutting tools for the hard milling process, they too will experience a considerable increase in their business activities and thus be able to create new jobs.

Dissemination and use of project results

2.1 Exploitable knowledge and its use

According to the performed work and the already described project achievements, some major key findings can be defined as the project outcome where special knowledge has been generated. These topics are described in the following including a short description of further exploitation and usage activities.

Enlarged knowledge of five axis hard milling technology
The enlarged knowledge of five axis hard milling technology specifies a better understanding of the hard milling process itself. With the parameters used and identified during the project work in combination with the applied tools enhancements regarding the attainable qualities can be achieved. The partners involved in this result can use the gained knowledge for their own production immediately (**End Users**), for their system developments **(Jabro, ModuleWorks)** and for advisory activities to help other companies with their hard turning processes (**IPT, Hemtech**).

Barrel tool technology
The milling technology based on a barrel tool geometry can considerably shorten manufacturing times. The technology can only be implemented succesfully, when tool geometry **(Jabro)**, process technology **(IPT)** and milling strategy **(ModuleWorks)** work together as it is a highly complex manufacturing technology. The partners involved into this result can use the generated knowledge to create new products and services for their customers.

Optimized hard milling machine tool
Hemtech will use the knowledge generated in regard to the machine tool components. This concerns the light weight spindle box as well as the evaluation of the dynamic behavior or the machine. Hemtech will use the knowledge to enhance its existing machine tool.

Damped work piece clamping
The damped clamping device is a development of **System 3R** which has already proven its capability to enhance process stability in other projects. The developments within the HardPrecision project mainly aimed at understanding the interaction with a hydrostatic machine tool. The developments will be used to further enhance the products of System 3R.

Production of high precision milling tools
The milling tool precision has proven to be one of the weakest links in high precision hard milling. Production methods to enhance the precision and tighten the tolerances of the ball end mill shape therefore are of vital importance for the improvement of the overall process technology. **Jabro** will use the knowledge generated within the project to further enhance its products.

PVD coatings for milling hardened tool steel
PVD coatings considerably increase the abrasion resistance of milling tools. The developments within this project aim at an adaptation of such coatings to the needs of high hard milling and further developments to improve these coatings. The knowledge generated will be used by **CemeCon** to improve its existing and develop novel coatings for milling tools.

In-machine measuring methods and technologies
In-machine measurement methods make it possible to replace in many cases application of coordinate measuring machines by measurement of work pieces in working space of machine tools immediately after machining. Measured errors of work pieces can be analyzed and applied for supervising and corrections of tools, machining processes and thermal dilatations of machines. It is supposed to offer these measuring technologies and the gained additional knowledge **(RCMT)** to all customers of high-precision **Hemtech** machines.

Knowledge of behavior of Acoustic Emission signals in the field of hard milling
In the field of hard milling the measurement of acoustic emission signals is not established. The measurements taken in the project lead to a better understanding of the process of hard-milling. The aim is, to use this knowledge at **Dittel** to improve the strategies for process stability, detecting tool wear and tool breakage.

Optimized process chain and milling strategies for demonstrator parts
The sample parts defined in the HardPrecision project are taken from real parts of the **end users**. Finding a way to enhance the process chain for the manufacturing of these parts is a direct way towards a better competitiveness of the end users. The four companies will use the knowledge generated to ameliorate their production of the sample parts and comparable parts in the future.

2.2 Dissemination of knowledge

Dissemination of project results was a major target for all involved partners during the entire duration of the project. Besides contributing to knowledge transfer into the European tooling industry, this procedure has also led to a much better adaptation of the project results to industrial needs. In the further steps, this will enable a better and faster use and exploitation of the project results for the consortium as industry experts already know about the developments in progress.

In order to attain a vast public of industry experts, publications were made sowing the aims and actual progress of the HardPrecision project. A list of major publications can be found in the following:

- At October 16th to 20th, the Fraunhofer IPT machine presented achievements of the topology optimization of fibre reinforced composite parts on the AIRTEC 2006 in Frankfurt.
- Prof. Klocke held a speech on "High precision five axis hard milling" at the 6th International Colloquium tool and die making in Aachen on September 24th.
- Results were presented at the Seco-Jabro Mould & Die Meeting in France (Q2-2006)
- Results were presented at the Seco-Jabro Mould & Die Meeting in Japan (Q4-2006)
- Snijders, J: Dynamisch bis ins kleinste Detail, in: NC-Fertigung 5/2006.
- Arntz, K.: "Hartfräsen pulvermetallurgischer Werkzeugstähle – aktuelle Trends und Entwicklungen", in: Böhler Journal "Best", 4/2007.
- Arntz, K.: Hartfräsen für den Werkzeugbau, in: Industriebedarf 1-2/2007.
- Snijders, J.: Hartbearbeitung neu definiert, in: Form+Werkzeug 5/2006
- Arntz, K.: Technological success factors in tool and die making, presentation at ISTMA World conference, Joensuu, 2007
- Press release for Euromold fair 2007 printed by: Formwerk, Stahlformenbauer, Form+Werkzeug, Industrieanzeiger, MesseKurier, Metall-Magazine, ETMM magazine
- Arntz, K.: Technologies in tool making – today and tomorrow, presentation at Uddeholm Automotive Tooling Seminar 2008 in Sweden
- Some results of the RCMT activities within the HARDPRECISION project have been published as a paper on the International Conference: Manufacturing, Intelligent Design and Optimization

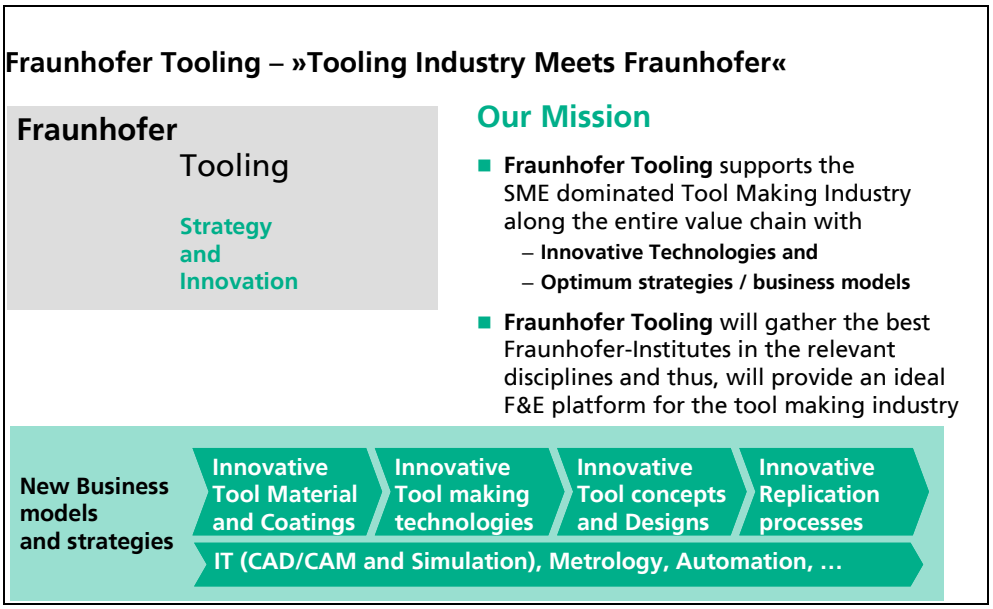
Machines, held in Karpacz (Poland) in March 2007. Authors and title of the paper are: Jaromir Zeleny, Michal Janda, Martin Novak: Continuous Evaluation of Machining Accuracy by In-Machine Measurements.

- Identical article was published in the Journal of Machine Engineering, issued by the Wroclaw Board of Scientific and Technical Societies in January 2007.
- Paper for the CIRP General Assembly Conference held in August 2008 in Manchester, UK is in preparation.
- Paper for the International Conference of precision engineering / EUSPEN held in Zurych, Switzerland in May 2008 is in preparation.

Since the Fraunhofer IPT and the other consortium members (especially Hemtech as project co-ordinator and machine tool manufacturer) participate at various fairs the partners used these kinds of "verbal" publication of the project idea and the respectively actual status of the project in personal conversations. In addition to this a poster and a handout of the general project idea and its objectives were available during the project and after at the Fraunhofer IPTs machine shop floor from the beginning of the project. The IPT has many visitors from the European industry (between 600 and 800 per year). In addition to this the employees of the Fraunhofer IPT take part in various conferences and exhibitions with industrial and research related topics informing the audience of actual projects.

During the 2007 Year, the "Hardprecision" horizontal spindle five-axis machine was equipped with "in-machine measurement" functions developed and tested by Hemtech and RCMT in cooperation with the M+H and Renishaw Companies. Other two machines, these being the vertical spindle, type LM1 milling machine and the horizontal spindle, type LM2 machine both with linear motors were equipped with "in-machine measurement" functions, tested in the RCMT Laboratory in Prague and demonstrated for university students and visitors from industry.

The by-far most important dissemination activity was the presentation of the project results at the Euromold fair where the Hemtech machine tool had a prominent place on the Fraunhofer booth. Being in hall 8 (major hall of the fair) and with 280 m² one of the biggest booths at the Euromold fair, this position gave the machine and the project a very prominent position, as can be seen in the figures below.



Vision of the Fraunhofer booth at Euromold

View of the milling machine prototype at the booth