


ADVANCED MANUFACTURING



**TECHNOLOGY**  
FOR CUSTOMER ORIENTED  
PRODUCTION OF  
**NATURAL  
STONES**

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## INTRODUCTION

There are a large number of companies operating in the field of marble quarrying, working and treatment. They buy big marble and granite blocks directly from quarries, cut them and deliver them to building companies. Then they are processed: either automatically machined to standardised sizes or manual finished to meet customer's design. Even though the machine can do all the hard work and, using grinding, big part of the fine work, the final touch has to be added by the craftsman. This is the main reason for design stoneware high costs and limiting factor for rapid prototyping technologies applications.

There is an increasing need for a new method for machining of brittle materials that will decrease the cost and increase the efficiency without compromising part quality. The solution of this practical task has been found. A new process is added to the traditional stone and processing technology with the dry high speed treatment. This paper summarises the overview of dedicated equipment and possible applications of dry high speed milling in stone industry.

Extended manufacturing example parts have been machined on the basis set-up of manufacturing systems. Example parts have proved, that as complicated 3D-object as a natural rose is practically manufacturable in marble by a five axis machine using dry high speed treatment. Resulting surfaces, milling mode finished for all tested natural stones are promising a new generation of products made out of marble or granite, 3D treated, with very high added value.

Each customary commercial CAD-CAM system enables to convert the 3D computer data directly to a physical object machined from marble and granite. Rapid prototyping potential is available now in natural stone market sector as in the metal machining sector.

Two demonstrator units, Small demonstrator for work pieces with dimensions 400x400x400 mm, Large demonstrator for work pieces with dimensions 1200x600x450mm have been approved functionally approved by experimental trials and field tests.

The dry machining strategy of natural stone at the high spindle speeds and feed rates proved extremely advantageous in industrial application such as facades, stairs, chimneys and heating decorations, lighting bodies and mirror manufacturing.

The aim of this article is to

- Introduce the development, specification and implementation of a new processing technology for natural stone and technical ceramics – dry high speed milling
- Demonstrate it's possible application
- To illustrate its business potential

## NEW PROCESS: DRY HIGH SPEED MILLING OF NATURAL STONES AND CERAMICS

In any machining process, a wear-resistant cutting edge separates material from the workpiece because of the velocity of the cutting tool edge relative to the workpiece.

When cutting metals, intense heat causes plastic deformation, producing chips or a curl of material. Brittle materials are different; they are machined by a process of fracturing the material not by a plastic deformation. The cutting edge crushes the materials just ahead of the tool edge as it moves through the

material. This forms small particles, resulting in powder as an end product, no chips as when cutting metal. The stone and ceramic cutting process do not generate high temperatures.

The focus on the conventional materials like metals is to control the heat; the focus on the natural stones is how to split the crystals and how to remove the dust. Due to the material properties we have a different splitting process. With the conventional materials we have during cutting constantly to deal with a crack so the cutting edge is not purely in contact. This phenomenon does not exist in natural stones. The cutting edge has to split the crystals direct. Cutting tools producer Jabro Tools has developed special tools out of sub micron grain carbide to achieve a strong and extreme sharp cutting edge for high speed cutting marble stones.

#### **5-AXIS HIGH SPEED MILLING CENTRE FOR NATURAL STONES**

LithoCerm 1 (Small Scale Demonstrator – SSD) is an innovative CNC 5-Axis machining centre for natural stone and technical ceramics. Manufacturing accuracy for small-scale parts is +/-0,01 mm. SSD has been developed with special efforts in the point of maintenance free machining and a high stiff machine conception. The machining of marble stone and technical ceramics under the conditions of dry high speed cutting needs a special machine concept. The machine, which is able to minimise micro vibrations, has been created in consideration of brittle materials machining specifics SSD is supplied with IBAG (HF 100 AI 50) high speed spindle, speed range up to 62,000 rpm and maximum power 7,7 kW. The spindle has a higher rigidity and a much higher stiffness in radial and in axial directions.

An advanced 3D control unit has been adapted to the system. The cell controller for both, small scale demonstrator and large scale demonstrator is a SINUMERIK 840Di with the following components:



*LithoCerm 1, Small Scale Demonstrator*

- Numerical Controller 840Di with Profibus (Siemens)
- Drive Unit SIMODRIVE 611U (Siemens)
- PLC Periphery SIMATIC S7/200 (Siemens)
- Monitoring ARTIS-CTM (Artis)

Some adaptation and development of additional functionality had to be performed for the cell controller in order to meet the requirements of the Litho Pro demonstrators and thus special laboratory NC software versions that incorporate the additional functionality and are not available on the market are being used in the demonstrators. The demonstrators will be equipped with sensors, measurement converters and the monitoring system in working condition.

The spindle needs to be driven by a SIEMENS System. Sinumerik 840 DI. Therefore the IBAG Standard Supply-unit could not be used. The interface shall be made via Profibus DP: the module ET 200 L shall be used for all entering and exiting signals, accepting sensor signals from the spindle and to control other equipment such as lubrication system, cooling system, valves. The profibus DP shall be connected direct to the driver. The lubrication system will be switched on and off together with the spindle start and stop. There is not any lubrication during stand still function. The standalone cooling unit will be delivered as well as the converter to drive the spindle. In order to meet



this requirements, IBAG had to make a new supply-unit consisting of the mentioned electric cabinet and with mostly new components being used.

**Large scale demonstrator LSD**



*Large scale demonstrator*

Technical Parameters are as follows:

- Stroke x – axis: min. 2000 mm, max. acceleration: 0,4 g, max. speed: 8 m/min
- Stroke y – axis: min. 1400 mm, max. acceleration 0,4 g, max. speed: 8 m/min
- Stroke z – axis: min. 800 mm, max. acceleration: 0,4 g, max. speed: 8 m/min
- C – axis: 360°, max. speed 35 min-1

- A – axis: 0...90°, max. speed 35 min-1
- Tool – length: up to 100 mm
- Cutting – force: max. 2.000 N
- Tool – diameter: 8 mm...40 mm
- Tool – length: up to 100 mm
- Work piece – weight: up to 2.000 kg
- Integration of the IBAG motor spindle HF 230.7 AI – 25 kW

**RAPID PROTOTYPING TECHNOLOGIES FOR STONE MACHINING**

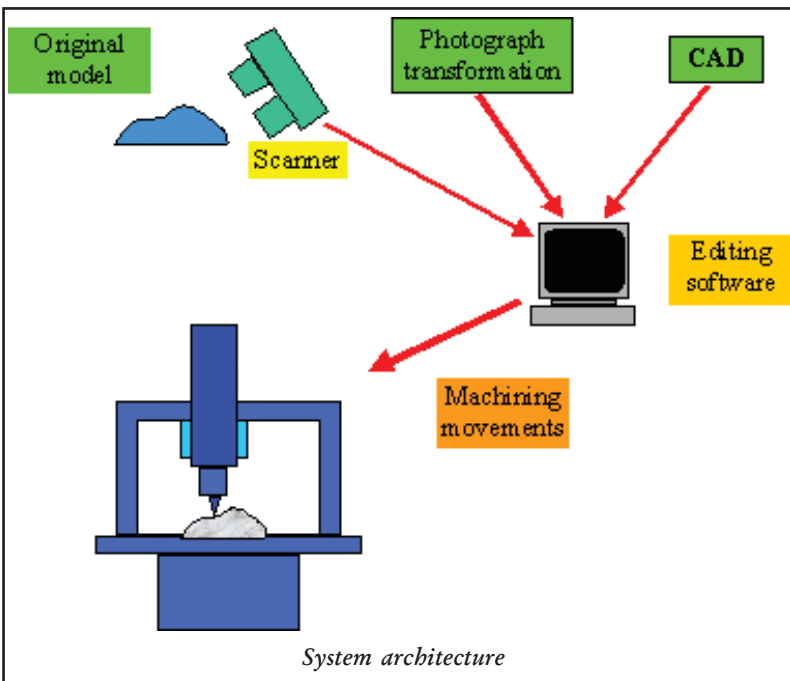
Especially in stone working and ceramics industries rapid prototyping technologies are very important due to high variety and high complexity of applications. LithoCerm 1 can be used for a broad range of production demands, including unique custom pieces, such as statues and memorials in artistry or parts of spinal column in medicine. It can be used for jobs, where accuracy and attention to detail is very important.

The CAD tools used are: shape modifiers, patterning techniques, 3D shapes from photographs, reverse engineering. Working from Photos, CAD databases, or data captured from existing forms via advanced scanning and digitising techniques, LithoCerm 1 sculpts with amazing precision and speed the most cost-effective method available for creating highly accurate 3-Dimensional objects and large sculptural forms

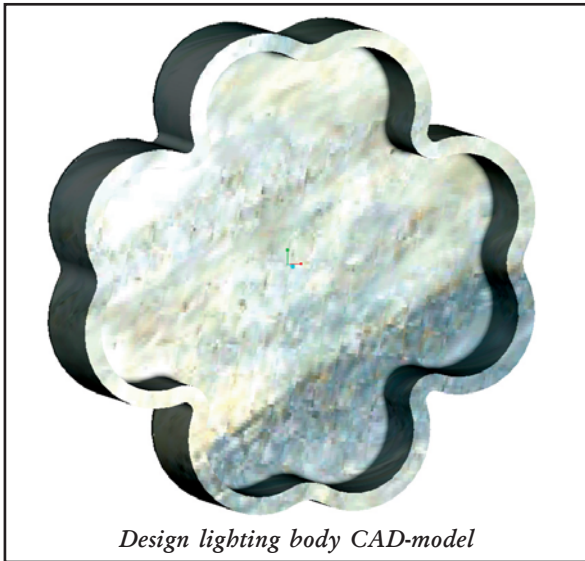
**POSSIBLE APPLICATIONS OF DRY HIGH SPEED MILLING IN STONE INDUSTRY**

The selected extended manufacturing example parts demonstrate SSD capacity, possible applications and limits by the production of very elaborate design parts.

The new process added to the traditional stone and ceramics processing technology makes possible the new products like lighting bodies with very individual design and other art products. The example of design lighting body CAD-model and the production of this lighting body are shown below.



*System architecture*



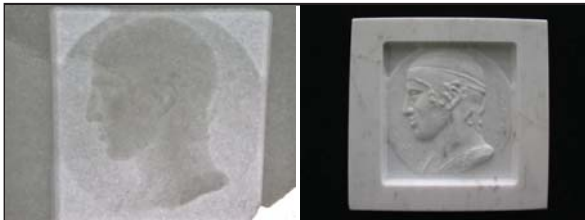
*Design lighting body CAD-model*



*Production of design lighting body*

**Artistical piece**

As one of example parts the artistical piece, scanned, produced with Thassos marble, has been defined in



*Artistical pieces - Charioteer - machined on SSD.  
Left - work piece material Thassos marble,  
right - work piece material Ajax marble*



*Artistical piece - Nifertiti - machined on SSD.  
Work piece material Ajax Marble*

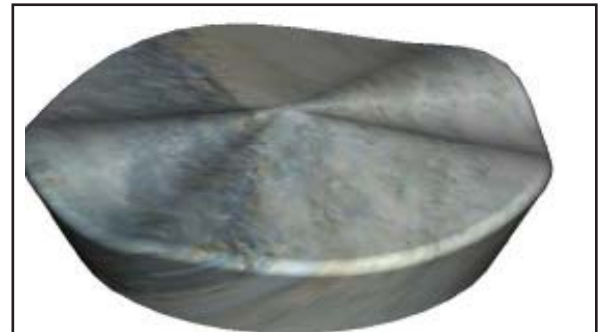
technical annex. We have tried to produce this part not only with Thassos marble, but also with Ajax marble. Furthermore we have machined another artistical part with Nifertiti relief. Charioteer machining time is about 25 minutes; Nifertiti machining time is about 20 minutes.

Surface quality of abovementioned example parts:  
Thassos marble: Rz = 15,28  $\mu$ m, Ra = 2,48  $\mu$ m  
Ajax marble: Rz = 14,16  $\mu$ m, Ra = 2,38  $\mu$ m

This surface quality corresponds milling mode finished for both marble sorts and Artistical pieces.

**Lamp body 1**

The "lamp" part below is a model of a lamp body with details that require five-axis manufacturing capabilities. The "lamp" part can be used with a common spot-light reflector either by itself or as the body of the lamp cover. Presented lamp design has been prepared for the "Stone+Tec 2003" Fair to demonstrate the SSD



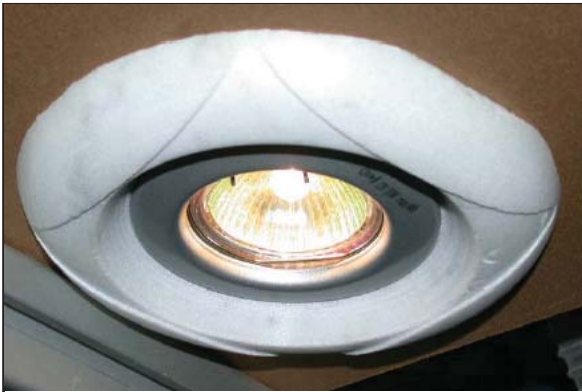
*Lamp body produced from Thassos Marble.  
Top - digital model,  
Bottom - lighting body's machining at the LithoCerm1*

manufacturing performance. The machining of this part takes only one hour.

**Lamp body 2**

The lighting body has been prepared at the LithoCerm1 using five-axis manufacturing capabilities.

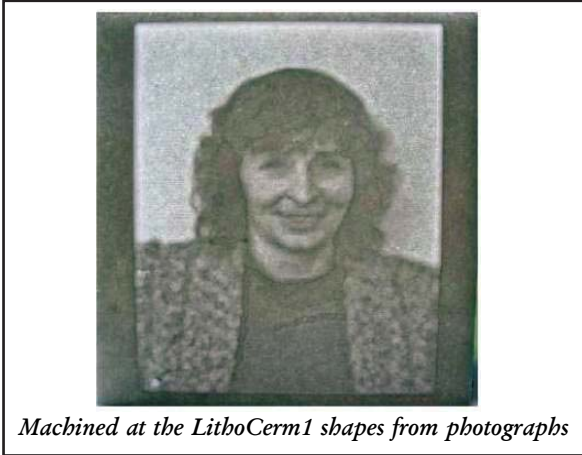
The surface quality of lamps produced from Thassos



*Lighting body produced at the LithoCerm1 from Thassoss Marble*

marble Rz = 6,5...11, Ra = 1,0 – 1,3. Milling mode finished, superfine.

### Shapes from photograph



*Mached at the LithoCerm1 shapes from photographs*

The shapes from photograph are automatically created on the basis of digital photos. These forms will be used in the future for the design lighting bodies. The homogeneous marble sorts have to be selected for this application.

### Celtic patterns



*The "Celtic Patterns"-Part produced from Thassoss Marble*

The presented on the figure 4.10.5 part is a general test for the variety of applications and decorations with Celtic patterns.

The surface quality of the Celtic Patterns-Part from Thassoss marble: Rz = 8-10, Ra = 1,5-1,6. Milling mode finished, superfine.

### Rose



*Digital model of the rose*

The "rose" part is the model of a scanned rose. A natural rose is both difficult to model and to manufacture comprising an enormous amount of detail. This part is used to show the limits of detail that is practically manufacturable in marble by a five axis machine. Digital Model of the rose is shown below.

The CNC-program for the manufacturing of the rose has been tested at the LithoCerm1. The first rose manufacturing trial was performed with plastic work piece, the second one- with marble one.

Furthermore following applications are possible:

- Mirrors
- Garden decorations



*Machining of plastic Rose at the LithoCerm1*





*Marble rose machined at the LithoCerm1, marble - Thassos whit*

- Unique custom pieces, such as statues and memorials in artistry

Restoration of historical works of art and archaeological and paleontological remains

**PERFORMANCE REPORT OF IBAG SWITZERLAND AG**

Motor Spindles being used for dry high speed milling of natural stones meet different conditions and have to be built special.

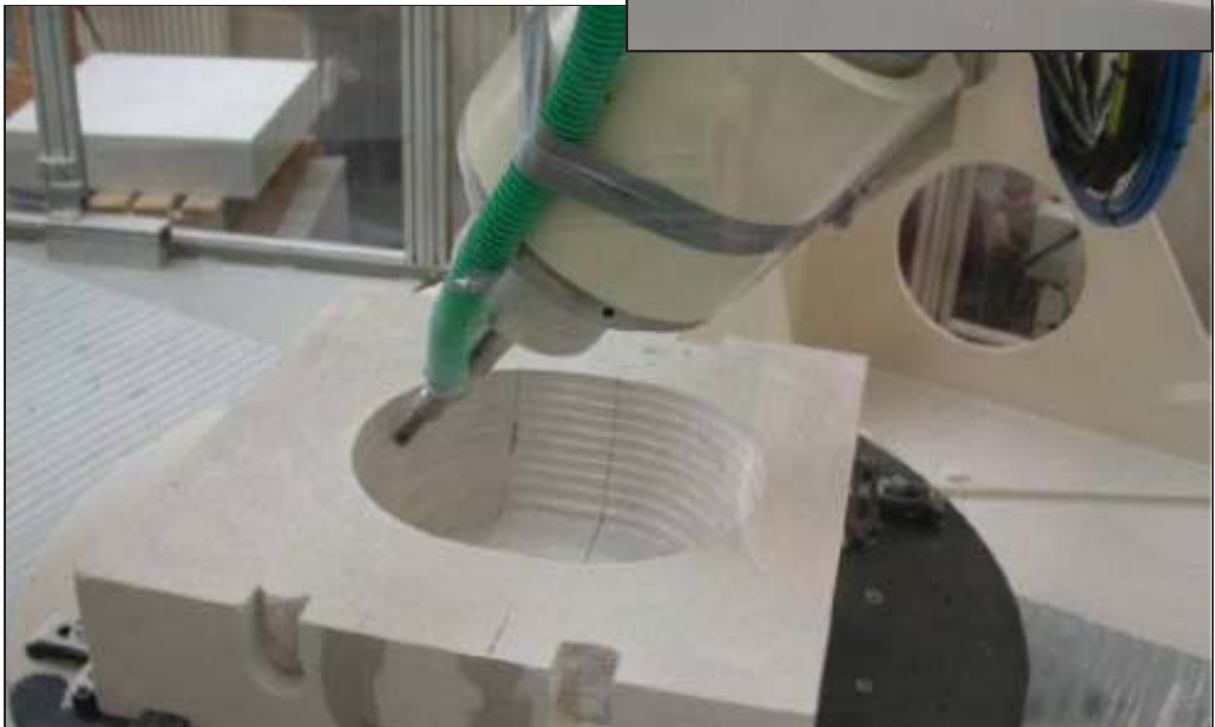
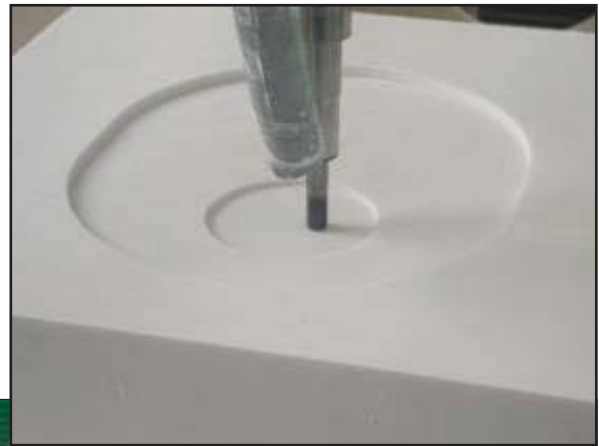
IBAG provides one spindle for the small and one spindle for the big demonstrator. In order to meet the optimal cutting speed for the various tools and tool diameter the spindles have to be very fast. Furthermore they have to be

able to run on a very low vibration level in order to get a long tool life and smooth surface quality on the work piece. They must be equipped with additional sensors for process monitoring and safety features.

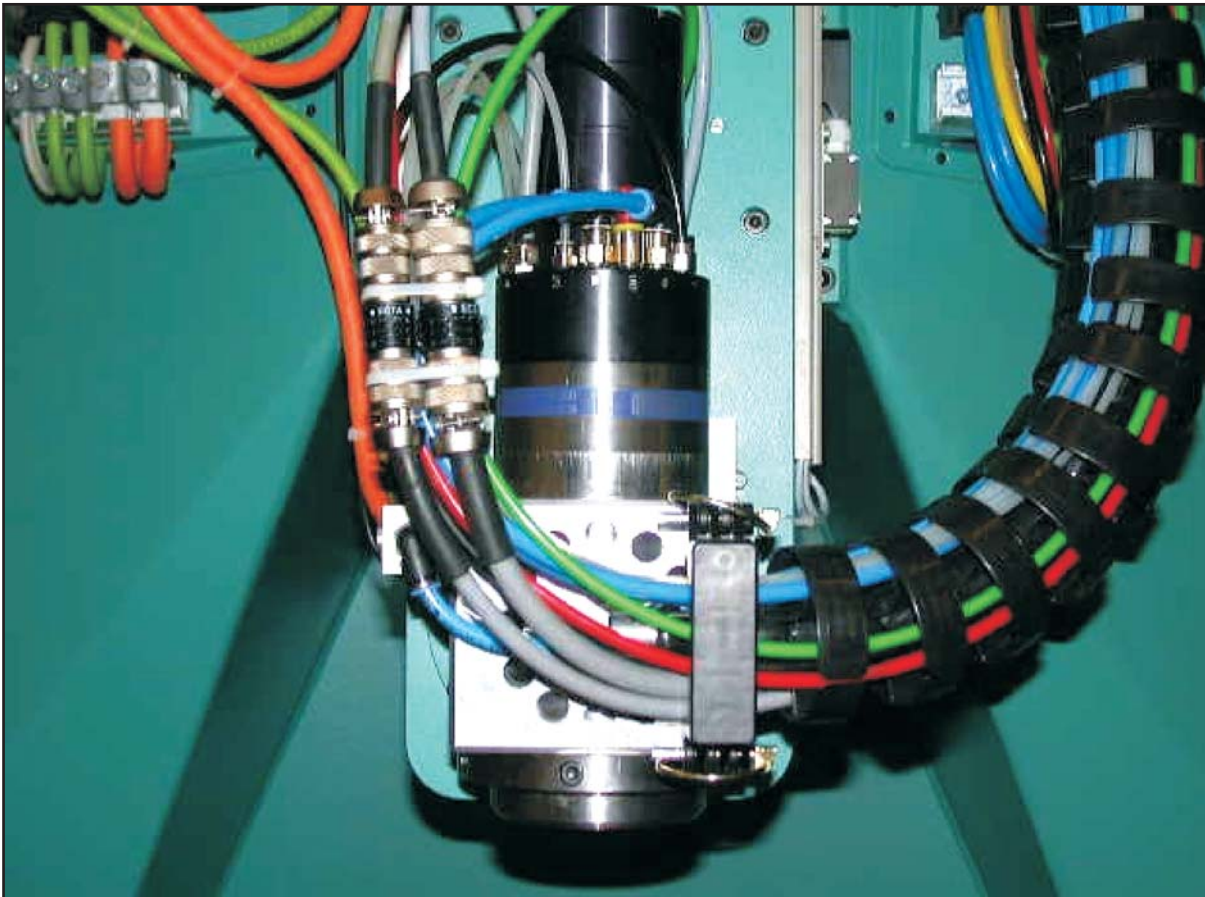
In order to meet all this parameter, IBAG had to develop a new type of Motor Spindle with much higher maximum RPM using Hybrid Ceramic Bearing and a new direct inlet lubrication system. The vibration level can be reduced by higher accuracy and quality of the rotating spindle parts and using the new developed nominal speed balancing system.

On the spindle for the small demonstrator is not enough space inside the spindle for additional vibrations sensors and therefore they must be placed on the outside flange or at the housing of the spindle nose.

The spindle needs to be driven by a SIEMENS System.



*Possible application: kitchen sink*



*IBAG-Spindle for Small Demonstrator*

Sinumerik 840 DI. Therefore the IBAG Standard Supply-unit could not be used. The interface shall be made via Profibus DP: the module ET 200 L shall be used for all entering and exiting signals, accepting sensor signals from the spindle and to control other equipment such as lubrication system, cooling system, valves. The profibus DP shall be connected direct to the driver. The lubrication system will be switched on and off together with the spindle start and stop. There is not any lubrication during stand still function. The standalone cooling unit will be delivered as well as the converter to drive the spindle. In order to meet this requirements, IBAG had to make a new supply-unit consisting of the mentioned electric cabinet and with mostly new components being used.

## CONCLUSIONS

The dry, high speed milling of natural stone, mainly marble of typical soft, middle and very hard kinds, show excellent results. Treatment parameters and resulting surfaces are promising a new generation of products made out of marble or granite, 3D treated, customized and with very high added value. The realization of a dedicated milling machine LithoCerm 1 for 3D, dry, high speed milling of brittle materials will allow process optimization and field-test in the near future. A final result should be the detailed description of the process.

A new process added to the traditional stone and ceramics processing opens new perspectives in world market. Rapid prototyping technologies used today in metal working industry are available now for natural stones and ceramics sector. This will influence stone products for interior use, facades and exterior use, ceramics products for medical, electrical, electronic use because high added value products can now be realized in industrial manner.

- The developed in Litho-Pro processing technology for natural stones is ready for the market
- The developed in Litho-Pro processing technology for technical ceramics needs some more research works. New research project will be proposed
- High speed motor spindles, milling tools and process parameters are Know-how and will be delivered from IBAG
- The construction of machine, CNC used, dust removing concept, postprocessor used can be produced in India

India is famous for its beautiful stoneware and we are sure that this technology can be implemented in India through Indian stone machinery manufacturers. 