DIGITAL MANUFACTURING APPROACH FOR FIVE – AXES MACHINING OF COMPLEX COMPONENTS

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Abstract. In world wide scenario where more and more businesses are distributed around the globe and competition becomes increasingly aggressive, small as well as large companies need to invent new and innovative products and bring them to market in a very short time. Reducing costs by applying local improvements to specific tasks, jobs or tools is no longer sufficient. This opens up opportunities for the companies to apply innovative means to collaborate in several areas of the product development process, particularly the design conceptual phase and more recently in the production phase where a whole shop floor can be virtually designed and simulated. All this take place before creating a physical product. The purpose of this paper is to show how a DM – PLM structure can be advantageously used within a product design and manufacturing process. To this end, the Centre of Competence in Manufacturing (CCM/ITA) emulates a company and a turbine impeller is used as a product sample.
***Keywords**: product lifecycle management, digital Manufacturing, machine tool simulation, five-axes machining.*

1. INTRODUCTION

Product Lifecycle Management (PLM) is a business strategy that enables manufacturing companies to achieve greater revenue and quality from their products and consequently profitability. Historically, PLM are product development orientated tools to achieve this business strategy.

According to Evans (2004), PLM is one of the four pillars of the information technology (IT) strategy of a discrete manufacturing industry. Besides managing its products lifecycle, all companies need also to manage communications and information with their customers through, for instance, CRM (Customer Relationship Management) (Ahn, 2003) and their suppliers, SCM (Supply Chain Management) (Hsu, 2005) and the resources within the enterprise, ERP (Enterprise Resource Planning) (Simonetti, 2002). According to Evans (2004) and Day (2002) the PLM benefits include:

- Reduce time to market;
- Improve product quality;
- Reduce prototyping costs;
- Optimize products;
- Reduce waste.

But from the manufacturing view point, what could be a PLM useful scenario? This question can be answered with the help of the digital manufacturing tools and methods which are being progressively introduced in the PLM portfolio. Thus from the PLM it can also be said: it consists of new business processes, design methods, organizational approaches and software tools that help manufacture industries to improve their competitiveness and product profitability by planning, designing, simulating and implementing better manufacturing processes.

Product manufacture involves a variety of complex and interconnected activities, from part and assembly processes planning to plant design, workplace ergonomics and material flow analysis as well as configuration control and quality planning. According to General Motors, the amount of information required to describe the manufacturing processes of a product is 1000 times greater than the information represented in the product design itself (Brown, 2004). All this information volume is necessary to communicate and to document the existent manufacturing complexity in a shop floor which includes processes and product manufacturability assessment.

Because of the volume and complexity, Digital Manufacturing or DM has become the solution to support and streamline all the mentioned activities with assistance of a robust database solution and simulation tools. Besides, PLM provides managing tools to control various aspects of manufacturing processes like resource inventory. Despite, Digital Manufacturing also provides to the companies a number of benefits even when it is used as a stand-alone tool, for example, the simulation of robots manufacturing cells and machine tools. Figure 1 shows the relation between PLM and Digital Manufacturing or DM domain (CIMdata, 2005).

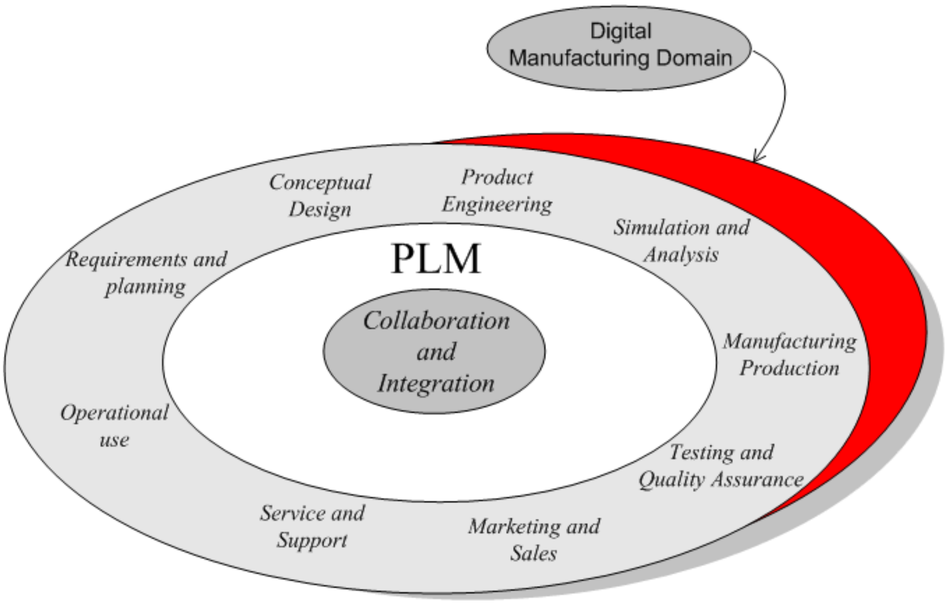

Figure1: Digital Manufacturing (DM) product definition and manufacturing in a PLM environment
Source: CIMdata, 2006

Frequently, the product data delivered to manufacture engineering is, basically threefold: CAD geometries, product requirements and product demand with this information, the manufacture engineering plan and execute the manufacturing process. DM approach enables a company to have a complete vision of the manufacturing processes including plant facilities and resources, material flow between machines or plants, workplace design and simulation, among others.

Although the use several tools like CAD/CAM/CNC , CAE finite element simulations, PDM data structure, ERP business rules and even Virtual Reality tools it can said that the Brazilian manufacture industry is still lacking behind their competitors in terms of DM and PLM usage. Only large aeronautics and automotive industries have started some developments in this area.

The purpose of this paper is to show how a DM – PLM structure can be advantageously used within a product design and manufacturing process. To this end, the Centre of Competence in Manufacturing (CCM/ITA) emulates a company and a turbine impeller is used as a product sample.

This paper is organized as follows: section 2 presents an overview of the digital manufacturing approach. Section 3 details the case study, whose results are discussed in Section 4. Finally, Section 5 presents the conclusions and next steps of the research.

2. THEORETICAL BACKGROUND

Surprisingly, few scientific literature texts could be found that compare conventional and DM approaches for the product manufacturing planning.

Basically, the publications found belong to digital manufacture systems vendors, consultancy companies and users of this technology (aeronautics and automotive industries). In Europe, particularly in Germany, DM is sometimes called Digital Factory (DF), where a bigger number of scientific contributions come from.

According to Bracht (2005), Digital Factory consists of the computer-aided tools necessary for the planning of new products and production plants as well as for the operation of the factories which are networked through a central database.

Rooks (1999, p.109), points out: “While hardly competing in volume with the popular ERP and MRP manufacturing control packages, the impact of simulation products is beginning to have a major impact not just on the planning but also on the control of whole factories”.

Digital Manufacturing and Digital Factory impacts in the overall product lifecycle by integrate the definitions of products, processes, and resources into a comprehensive and consistent manufacturing solution.

It is primarily focused on supporting the portion of the lifecycle that is centered on manufacturing planning and manufacturing engineering activities as shown in Fig. 1. It also simplifies the boundaries between PLM and enterprise resource planning (ERP), two primary areas of IT investment for industrial companies, facilitating the development of integrations between these two important enterprise solutions (CIMdata, 2006).

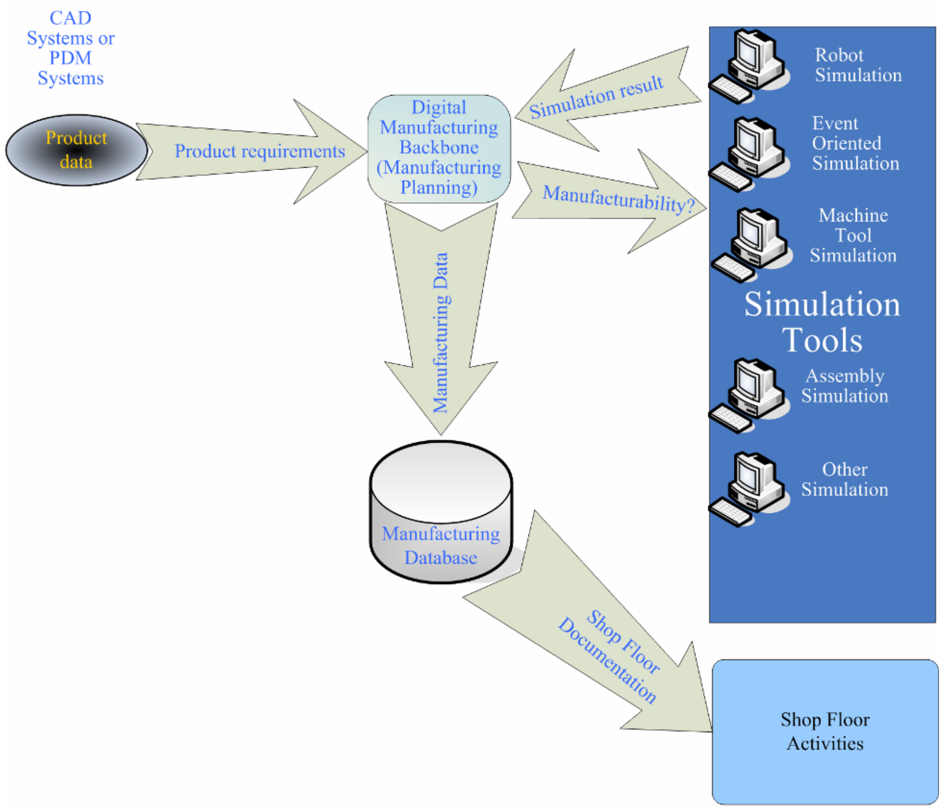

Figure 2: Digital Manufacturing common workflow

As can be observed from Fig. 2, DM requires a number of simulations and, prior to that, the models to be simulated. One of the major challenges within this scenario is the construction of the machine tool model. That is the reason for addressing this topic in the following section.

2.1. MACHINE TOOL SIMULATION

In the last two decades, CAD/CAM software houses have provided toolpath verification software that enables the shop floor operators to try out only the movement of the cutting tool across the workpiece. Currently, the application software has evolved to permit simulation of the entire machining system including workpiece, tool holder, spindle, rotary tables and fixture devices.

Machine tool simulation software uses 3D graphical technologies to model and animate the complete NC machine tool and its environment on a computer. The software processes the actual machine input and simulates all movements of the machine components, including the axes, heads and tools, in order to detect collisions between any moving or stationary components. A simulation sample frame is shown in the Fig. 3.

According to Nathan (2000) the benefits of machine simulation are:

- Detect collisions between all machine components including heads, axes, pallets and tables;
- Preview machining operations by simulating movements of all machine components;
- Train new programmers and operators;
- Validate post processor configurations;
- Use as a presentation and demonstration tool;

Some important factors must be taken into account when selecting a machine simulation product, according to Nathan (2000)

- Multi-window viewing capability: it is important to visualize and check the machine movements with respect to the current machined stock shape, otherwise, the collision detection might be misleading . The software should perform simultaneous, single-window material removal and machine simulation.
- Easy and non-programmatic interface: the machine modeling capabilities should be simple and flexible and the software should accept standard 3D CAD models as the machine components or which provides a non-programmatic interface for machine definition.
- Fast and smooth animation: for a realistic simulation of the machine tool, the software should support smooth animation using advanced 3D graphics capabilities.

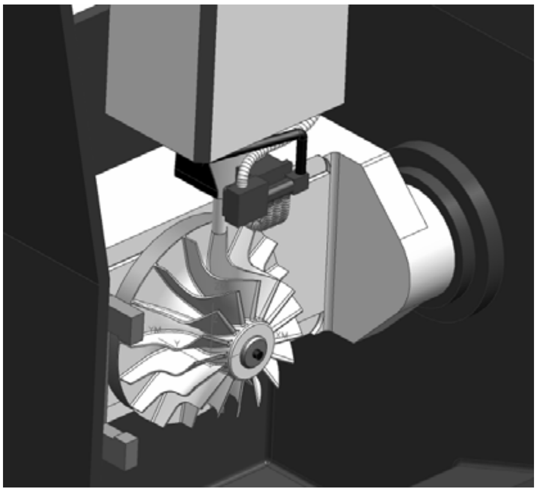

Figure 3.Simulation of machine tool used to validate an impeller manufacturing process (Silva, 2006).

3. CASE STUDY

This section describes a DM case study developed at CCM – ITA: the problem is set,, the proposed solution is detailed as well as the results obtained by application of the DM proposed solution.

3.1 PROBLEM DESCRIPTION

Gas turbine design is an important issue at ITA – Technological Institute of Aeronautics – since its foundation at 1950. One of these gas turbine designs developed at ITA has shown up the necessity to manufacture a compressor impeller component, whose functional characteristics have been tested through CFD (Computer Fluid Dynamics) simulation. But, the feasibility of its manufacturability was not completely certain with the resources and facilities available at ITA (e.g. a high speed, five-axis machine centre). This question has turned up because of the component dimensions that were very close of the machine tool limit dimensions as shown in Fig. 4.

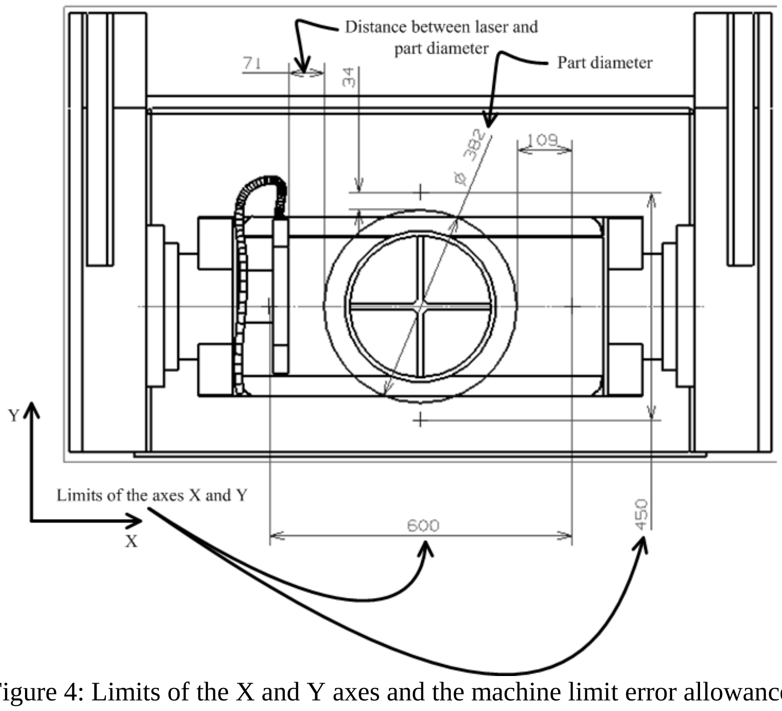

Figure 4: Limits of the X and Y axes and the machine limit error allowance.

For such a big part, it was not out of question the possibility that in the machining process, some functional axis limit of the machine would be overrun or even some collision between the part and the machine components would occur. Once proved one of these effects, naturally the machining of the impeller would be jeopardized or worse still, not possible at all.

3.2 PROPOSED SOLUTION

Due to the problem described above, the ITA Digital Manufacturing group has proposed the creation of a virtual machine tool. This virtual machine tool would be used for simulating and validating the machining process of the turbine part. Figure 5 summarizes the necessary steps to be followed in order to build the virtual machine tool up.

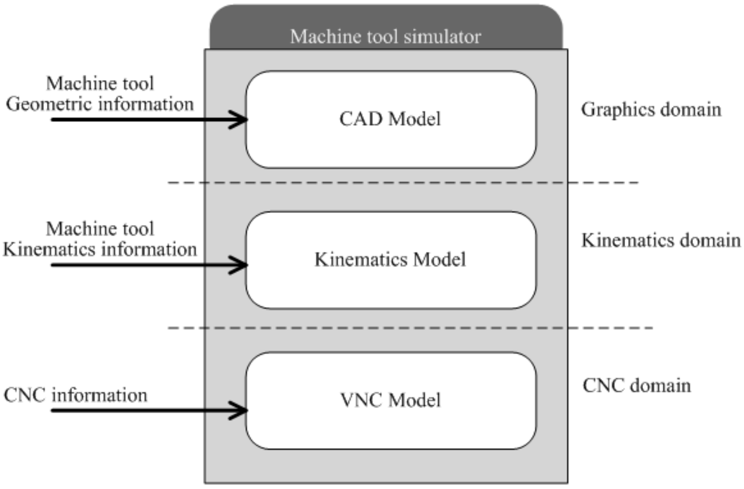

Figure 5: Machine tool simulator basic components

Each of the steps shown in Fig. 5 is detailed as follows.

CAD Modeling

In order to carry out this activity, the machine tool documentation was consulted and found the necessary information for elaborating the CAD model of the machine tool. Furthermore, some measurements were done straight from the real machine to render the virtual model more complete. Then, the main machine tool components were modeled in a total of fifteen components. The criterion for choosing which components would be modeled was based on fact that such a component would be within the working volume of the machine tool, thus avoiding any possible collision. This explains why coolant and tool measurement system components were included in the CAD model. The CAD modeling was executed with the aid of the UG NX4™ CAD software from UGS Corp. The CAD machine tool model is depicted in Fig. 6.

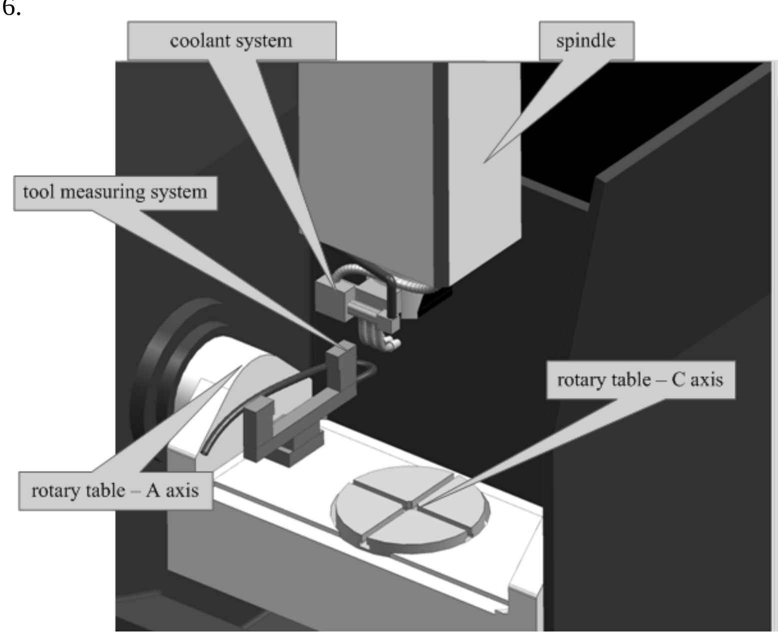

Figure 6: CAD Model of the machine tool.

Kinematics Modeling

The kinematics model of virtual the machine tool has been built up with the aid of the kinematics module of the machine tool builder software of the UGS™ Corp. The kinematics model is constituted of the restrictions and degrees of freedom of the machine tool axes as shown in Fig. 7.

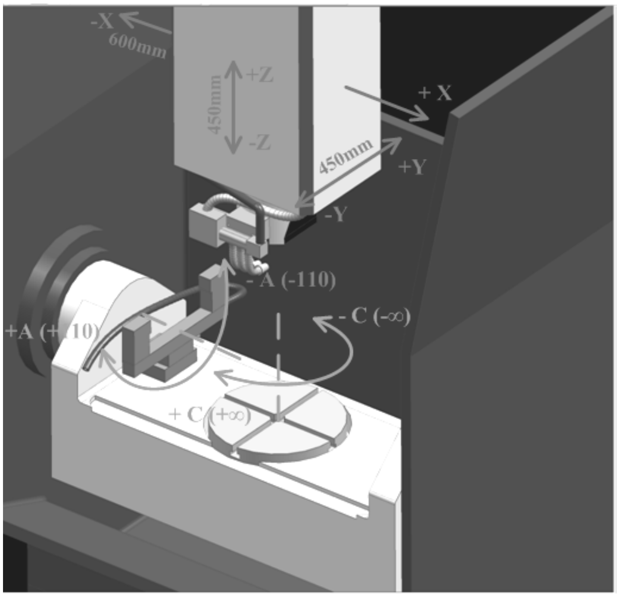

Figure 7: machine axis, degrees of freedom and constrains.

VNC Modeling

The last step of the model listed in Fig. 5, it is the creation of the VNC (Virtual Numeric Control) which is used for controlling the machine movements and software routines as a real numeric control would do. The VNC reads a CN program that would be downloaded to the machine tool controller and executes it – virtually – by means of graphic resources, routines and movements that would be part of the real process. The TCL (Tool Command Language) has been used to construct such a virtual numeric control.

Uploading of the components in the library

The uploading of the CAD, kinematics and VNC models in the UG NX4™ library has concluded the creation process of the machine tool (Hermle C600U) simulator. This allows other users to access and use the simulator to both check and validate their machining process.

4 CASE STUDY RESULTS

This section presents the main findings of the virtual machine tool operation (which is equivalent to a simulation). The findings are threefold: related to the product, fixturing design and machine operation.

4.1 RESULTS RELATED TO THE PRODUCT

Thanks to the simulator, collisions between the impeller and machine components were prevented. Therefore, the part manufacturability as far as collision is concerned has proved to be feasible. The simulation has unveiled a major problem with CAD model of the gas turbine component. This is described with the aid of Fig. 8.

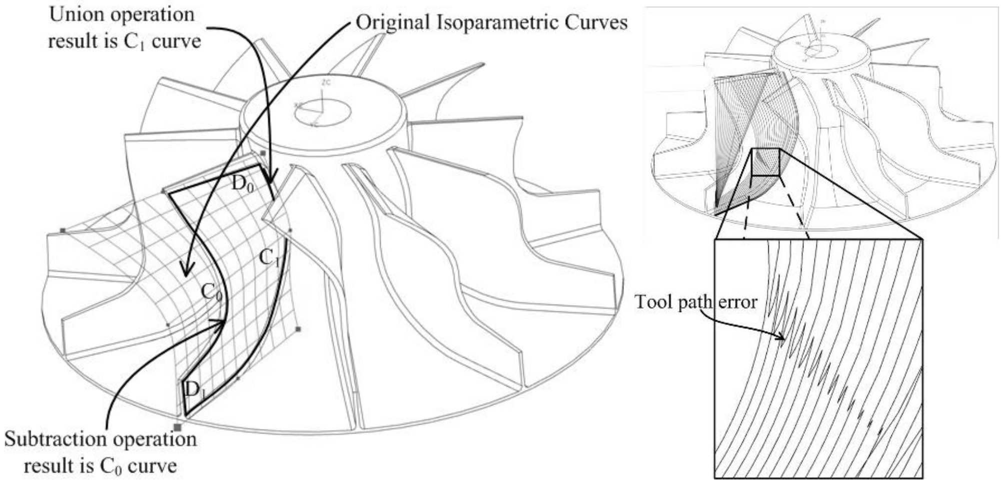

Figure 8: Boundary curves generated by Boolean operations C_0, C_1, D_0 e D_1 and the resultant tool path.

The impeller geometry built up through hybrid modeling technique (B-Rep: Boundary Representation and CSG: Constructive Solid Geometry), it has been verified a misalignment between the new created boundaries surface and original iso-parametric curves. Figure 8 shows the generated contour curves using Boolean operations, respectively C0, C1, D0 and D1. In this specific case, the resultant tool path would have abrupt movements verified in the simulation of the machining process; consequently the machining operation would generate gauging and bad finished surface.

The adopted solution for solving this problem was to model a new surface using the sweep surface modeling techniques. Two guide curves – C_0, and C_1 – and two profiles curves D_0 e D_1 were used to generate the new parametric surface, avoiding undesirable cutting tools movement over the surface Fig. 9.

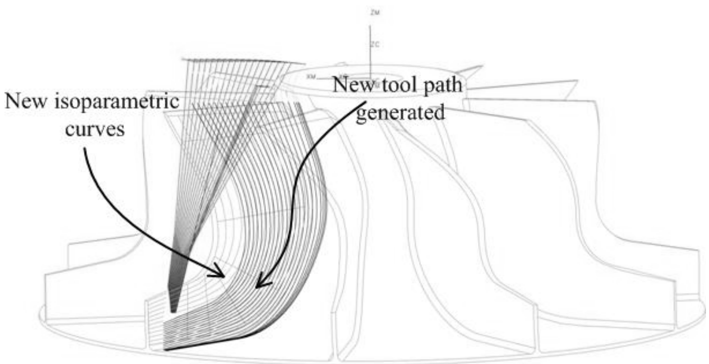

Figure 9: Newly created surface and tool path based on simulation findings.

4.2 RESULTS RELATED TO THE FIXTURING DESIGN

Besides anticipating virtually process mistakes of the turbine impeller, the 3D model has been used as aid for fixturing design. The researchers and technicians have used the 3D information of the virtual machine tool to discuss device design options to adequately clamp the component. It is worth mentioning that this approach is very interesting to globally distributed teams and suppliers as this – portable – information could be shared among the people involved in the project. Some designs possibilities have been searched among potential suppliers, and the final fixturing design, shown in Fig. 10, has been validated in the simulation environment

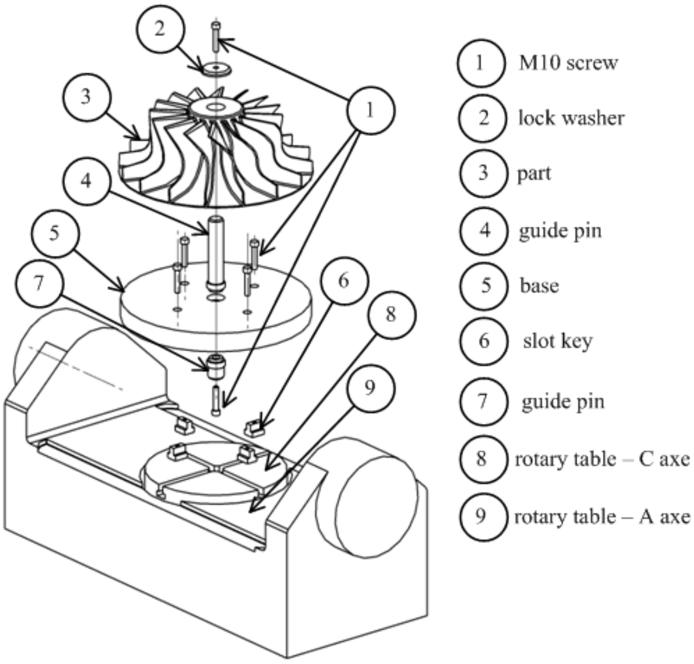

Figure 10: Fixturing design chosen to clamp the impeller on the machine tool table

4.3 RESULTS RELATED TO MACHINE OPERATION

The real machine tool operation executed by the technicians of CCM-ITA has also benefit from the simulated environment. They were offered the possibility to check the machine tool behavior well ahead of the real manufacturing tasks. Thus, the DM has opened up a new communication channel between the CAM users and the technicians that actually execute the CN program; consequently, a number of potential problems could be avoided. Thanks to the machine simulator, it has been possible to prevent collisions among the machine components and the machined part as well as to analyze and optimize cut strategies. It has also been obtained a fidelity model about the working volume of the machine tool at its programming stage.

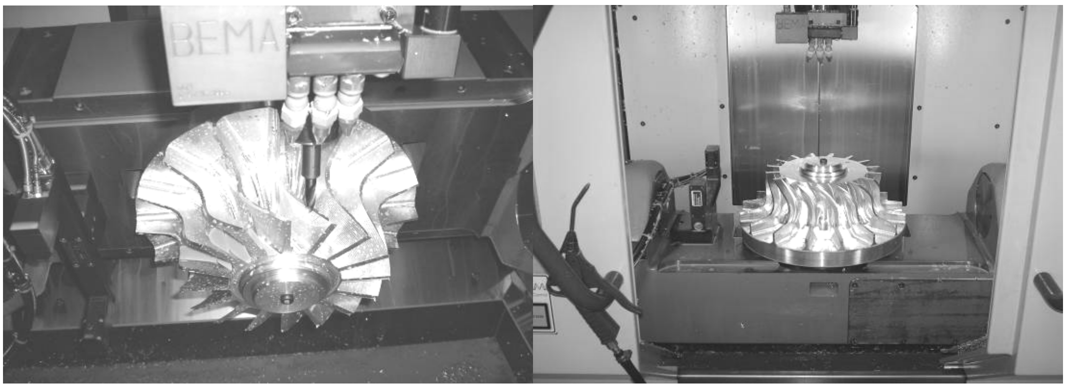

Figure 11: machining of the gas turbine component

5. DISCUSSION AND CONCLUSION

This paper has discussed – in theoretical basis – the PLM role within the product development process and it has identified the DM – Digital Manufacturing – as one of its enabling technologies. In order to prove the benefits that might be achieve through DM, a practical and challenging case study has been presented in detail. The part to be machined is a turbine impeller which possesses a very complex geometry that would demand a considerable time and effort to be machined directly in the "real" world. As an alternative, the impeller has been machined in the virtual world that was built up entirely: machine tool (geometric and kinematics models), CN controller and the part itself. The benefits of the DM approach could be sought into three areas: product, fixturing and machine operation.

6. ACKNOWLEDGEMENTS

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