PROJECT FINAL REPORT

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"Innovative proactive Quality Control system for in-process multi-stage defect reduction"

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

4.1 Final publishable summary report

1. Executive Summary

The main objective of MuProD project is the development of a new Innovative Quality Control System that will drastically change the current concept of End Of Line (EOL) quality control, going beyond currently established methodologies such as Six-sigma and SPC. It will prevent the generation of defects within the process at single stage and the propagation of defects between processes at multi-stage system level. This Quality Control System will be proactive, offering three different solution strategies to avoid End Of Line defects:

1. Elimination of the predicted defect through adjustment of process characteristics by proactively intervening on the inputs to the process (process parameters, etc.),
2. On-line reworking of the product in order to eliminate the defect,
3. On-line workpiece repair through defect elimination at consecutive process stages.

With the aim of achieving this concept of the proactive quality control system solution, the Consortium has identified and planned the following Scientific and Technological Objectives:

I. **To define the MuProD Quality Control system** with respect to external intelligent sensoring and inspection techniques, intelligent external actuators, monitoring and prognosis models, integrative correlated multi-stage solutions and proactive control applied to the real-life **Use Cases** that the project will cover.

II. **To integrate intelligent and synergetic sensors** for in-process multi-data gathering and **in-process inspection techniques** for product multi-data gathering into the production chain. And to develop an Information Sharing Platform**,** to integrate the carried out developments into a common platform

III. **To develop intelligent external actuators** to adjust the process depending on the process variations, compensating deviations in real time.

IV. **To develop monitoring and prognosis models** for process/fixturing/machine level that integrated will predict the defect in the process, will prevent the defect generation by in-process control and will be integrated into the operation planning/execution.

V. **To develop new integrative solutions for proactive quality control** in correlated multistage systems to prevent the propagation of defects to the end-of-line by on-line rework and product deviations compensation.

VI. **To develop a proactive control** to offer three different solution strategies at process stage level: process characteristics adjustment, reworking or scrapping of defective parts.

VII. **To construct Demonstrators** in three Application Domains, integrating the technological developments for demonstrating in real-life Use Cases the applicability of the MuProD approach.

The combination of these technologies (called at the end of the project as the ZERO DEFETCT MANUFACTURING METHODOLOGY: ZDM2) has made up a universal system able to be integrated into different production processes. Its feasibility has been demonstrated in machining and assembly processes at both macro and micro product scales. The integration of the in-process Quality Control system into the production chains will minimize the amount of defective part production, increasing process capability in mass production, and equivalent reduction of defect amount in small-lots and customized product manufacturing. Application domains in the project have included emerging strategic European sectors such as the production of electrical engines for sustainable mobility, large-part manufacturing for the wind power sector and the production of customized micro-intravascular catheters as high value medical products for the aging society.

2. Summary description of project context and objectives (not exceeding 4 pages).

Traditional quality control methodologies, such as Six Sigma (used across the manufacturing industry as a way of improving processes through the systematic removal of defects) or SPC (method of monitoring a production process through the use of control charts) methodologies among others are currently used in mass production. Their main drawback is being End Of Line methods, as they are based on off-line inspection of defective products, usually carried out at the final stage of the manufacturing chain, having already accumulated all the possible defects of the production chain, and lacking the ability of acting as in-process quality control systems. Consequentially, if a fault occurs in an early step of a long process chain, a number of subsequent operations are performed on the defective work piece, which consume resources and generate waste but do not add value. Once the defect is detected during end-of-line testing, the defective product can only be recycled.

Traditional quality control and Six-Sigma approaches show poor integration of the information gathered from sensors with process and system knowledge-based models. Traditionally, only simple data sets are processed to obtain black-box models characterizing the process response under variations of the process conditions and parameters. These models do not help in presence of unexpected disturbances on an item-to-item basis, but only enable to forecast the impact of known process deviations on the production of defective items. These tools are typically used post-process for identifying “out of control” process conditions or off-line to identify proper process capability improvement actions.

Many developments around adaptive techniques are being carried out to adjust the process inputs to meet final requirements, but these solutions do not take into account the system level dynamics, thus they do not offer solutions throughout the manufacturing chain.

Industry is demanding solutions to avoid End Of Line (EOL) failures, solutions able to predict the defects before they are generated and solutions to immediately react and act over the generated defects when they are detected, without having to wait until the final stage of the manufacturing chain.
Industry has to face manufacturing targets that are even more challenging when they have to deal with new complex products of bigger/smaller size or made of new materials and with more severe quality requirements. To this purpose, industry is demanding new flexible technological solutions to enable the on-line inspection of such products, since the only use of time-consuming off-line inspections performed by CMMs (Coordinate Measurement Machines) is not economical any more. These measured data must be the base for the generation of models that can predict what will happen in the process.

Small-lots producing companies are requiring new quality control techniques and methods that instead of being based on process capability concept (valid for mass production but not so applicable for small or unitary batches) are based on new concepts adapted to their needs.

Industry cannot achieve these solutions themselves since in-line-metrology controlled processes are not available on the market and require a high effort of interdisciplinary engineering, design, modelling and programming activities to be developed. Whereas up to now manufacturing industry has been working on the process and machine optimisation or implementation of different methods and monitoring systems, no on-line and in-process proactive quality control system exists yet.

Therefore MuProD system will solve the current limitations that are observed in classical Six Sigma approaches:

1. In-line, in-process control is possible but only considering one process signal at a time and very simple statistics on this signal (mean, variance, range).
2. Six Sigma does not incorporate process adjustments during the execution of a process, being limited to process monitoring with very simple feedback, such as “the process is in control or out of control?”
3. Six Sigma does not consider the possibility of including intelligent adaptable fixturing systems.
4. Workpiece based monitoring (Statistical Quality Control) is only implemented by using post process product inspection, therefore the workpiece is not used as an in-process sensor and defects are not predicted and prevented.
5. Statistical Quality Control only relates to feature whose specifications are dimensional (diameter, hole length, surface roughness, etc.). Geometric features cannot be tackled with SQC approaches.
6. On-line rework via interaction with the machine control is nowadays impossible.
7. Currently available on-line defect repair policies do not include product repair through compensation at downstream correlated process stages.
8. The analysis of the impact of local defect management policies on the global process-chain logistics, quality and economic performance is completely neglected

Technological advances in sensoring have enabled large variety of process signals to be gathered real-time during the process execution at extremely high acquisition rate. The main open scientific and industrial issue is how to synthetize such heterogeneous, multi-source, multi-scale signals data for advanced proactive process control purposes. Nowadays, no solutions to this issue are available on the market. However, high speed computing processors are available, thus enabling advanced models to be integrated on-line to proactively drive process control. The **revolutionary MuProd Quality Control system framework provides the tools to gather and fuse the different process signal patterns, to predict the generation of defects basing on the coupling between these signals and in-line workpiece geometry metrology data and to proactively control the process to prevent it to generate the predicted defect**. It will be a universal solution adaptable to different size batches, from mass production to small-lots, even to unique customized parts.

In mass production contexts, high throughput is required, and therefore repairing the product on-line may negatively affect the production rate of the system. In the MuProD framework, repairing items in line is performed by means of two possible actions: (i) rework the part in the same clamping by interacting with the machine controller or (ii) adjusting the process parameters at the downstream correlated stages to eliminate the defect. The first action entails a re-processing of the part at the machine thus affecting the process cycle time, while the second action only entails the adjustment of process parameters at the downstream stages, without significantly affecting the process cycle time, thus it is directly applicable also to mass production contexts.

Concerning the first option, in MuProD the decision on the convenience of reworking the product on line is taken coherently with cycle time constraints, with the overall system logistics dynamics and after an evaluation of the economic benefits of product rework. Clearly, on line product rework increase the machine cycle time and may affect the production rate of the system. However, if the machine where rework is operated is not the bottleneck, the effect of product rework on the production rate may be very minor, while having a great positive effect on the product quality, thus making in line rework convenient. In the MuProD framework such decisions are taken by the process-chain analyser that estimates the economical convenience at system level of local rework decisions.

Summarizing, the MuProD approach allows to **prevent defective parts production and propagation** instead of identifying defective items after they have been produced, thus allowing drastic increase in the process capability, also for small batches down to “one-of-a-kind” customized, make-to-order products. The innovations brought to the market by MuProD with respect to existing solutions are highlighted in ***Figure 1***.

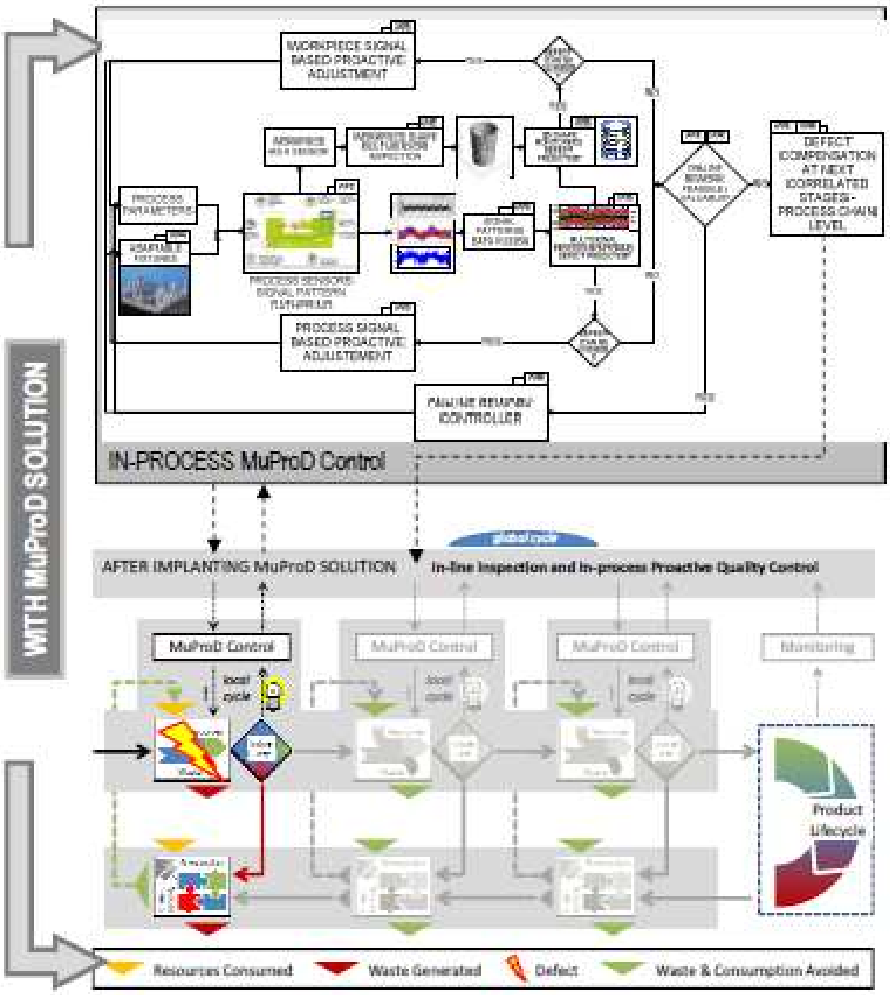


Figure 1: Vision of MuProD Project

Three industrial end users have participated in the project with the main goal of carrying out the demonstration activities through **Real-life Industrial Use Cases** from three Application Domains (AD). The Application domains include emerging strategic European sectors such as:

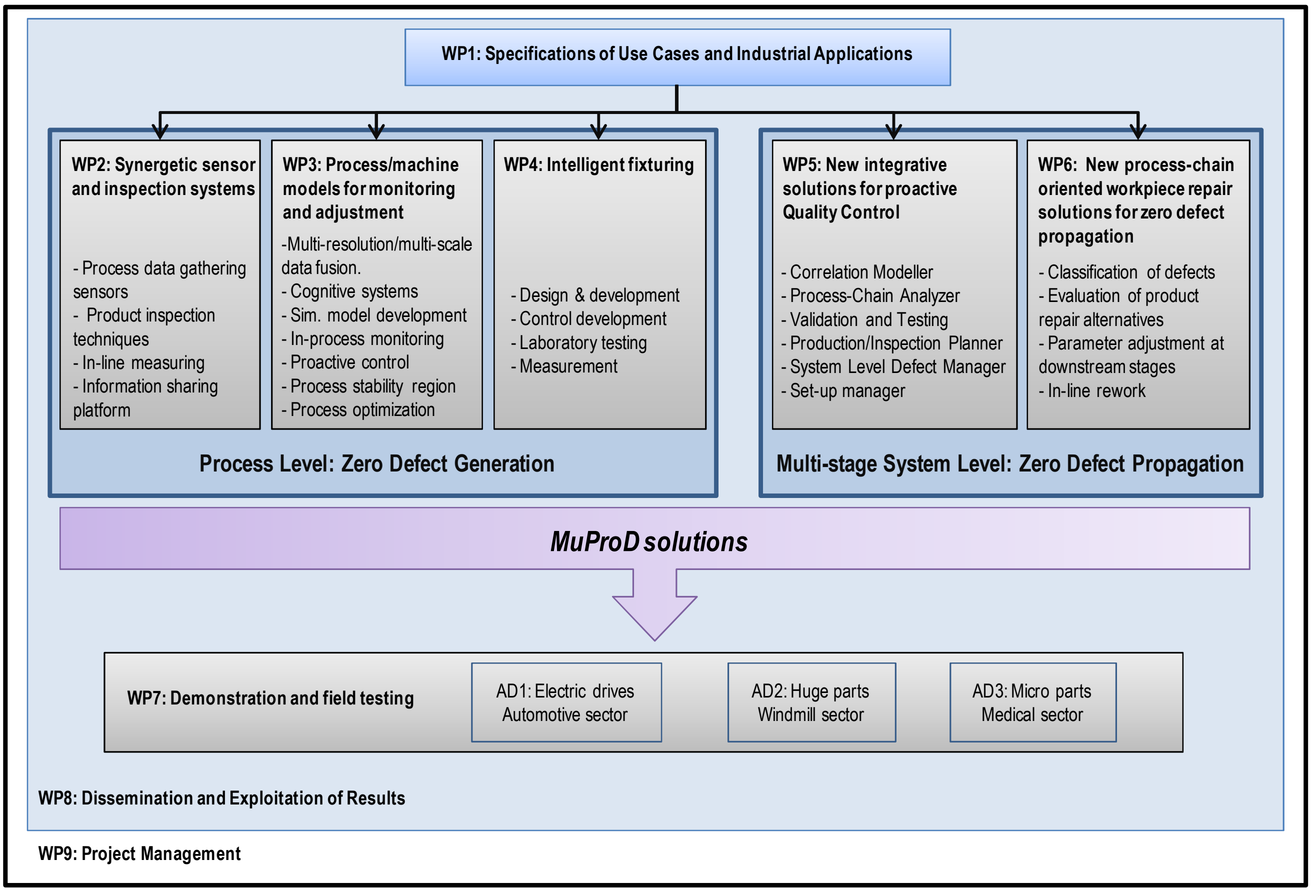
- **AD1, MuProD Industrial Case Study I: Assembly chain of an electrical drive for sustainable mobility.**
  The partner responsible for constructing this demonstrator has been **Robert Bosch GmbH.**
- **AD2, MuProD Industrial Case Study II: Precise large-part machining of components for the gearbox of windmill-building industry.**
  The partner responsible for constructing this demonstrator has been **Gamesa Energy Transmission.**
- **AD3: MuProD Industrial Case Study III: Sustainable Micro-production of micro-intravascular catheters as high value medical products for the aging society**
  The partner responsible for constructing this demonstrator has been **ENKI, Srl.**

The demonstration of MuProD results has the following aims:

1) To **integrate the MuProD system into** current production plants, in real-life situations to demonstrate their validity and use for nearly zero-defect productive processes.
2) To focus the research activities on some **specific and emerging sectors** of the European industry.
3) To focus the research tasks to those Industrial Use Cases from the very beginning of the project.
4) To define **three demonstration scenarios** for applying the breakthrough MuProD system for proactive Quality Control system for **constructing three respective Demonstrators.**

3. Description of the main S&T results/foregrounds

The research activity in MuProD has been tackled from the WP1 to the WP6, being the distribution of WP as indicated in the next schema:



- **WP1** aimed to identify the specific features and characteristics of the three industrial Use Cases and to define the requirements for the MuProD proactive quality control system.

- **WP2** aimed to identify and develop synergetic process data gathering sensors and innovative inspection techniques for product inspection. In-line experimental data measurement was carried out. An Information Sharing Platform was developed.

- **WP3** aimed to develop process/machine models for monitoring and adjustment that based on different data analysis techniques (statistical and cognitive systems) developed predictive models for zero defect generation at process level.

- **WP4** aimed to design and develop intelligent clamping or fixturing offering new innovative features such as to adapt themselves to the requirements and needs of the process and part.

The first part of the project, namely WP1-4, focuses only on one single process stage, which can be assumed as isolated from the rest of the production system. And the developments go directly linked to the prevention in the generation of the defects. In contrast to the previous WPs, WP 5 is the first one that takes into account the multi-stage behaviour of the production systems and therefore the interaction between the different processes. Thus, the regarded process cannot be treated independently of the other process stages any more. The work in these WPs are directly linked to the propagation of defects during the different stages of the process.

- **WP5** aimed to develop new integrative solutions for the development of the proactive Quality Control solution at multi-stage system level for zero defect propagation.

- **WP6** aimed to develop new process-chain oriented workpiece repair solutions, classifying the production defects, evaluating the repair alternatives, defining the parameter adjustment and determining if rework is or not feasible.

- **WP7** addressed demonstration through the integration of previous WP developments into the manufacturing chain and subsequent validation through and overall assessment.

The results of each of these WPs are described now:

WP1: Specification of Use Cases and Industrial Applications

In this WP, the MuProD Consortium has analysed the three industrial cases and has defined in detail the Use Cases of the three Application Domains. The specific characteristics and features of each of the use cases have been identified, characterizing their common features as well as the features that are specific only to one or some of them. Besides, the current process and production chain have been analysed, in order to establish the reference point and values that will be used at the end of the project to measure the results obtained with MuProD solution.

With this vision, in this task the following activities have been carried out:

- To define common and specific characteristics for the different use cases.
- To define the reference process capability or defect production of the different use cases.
- To analyse the main features that most affect the process and final product.
- To define the aspects to be improved to achieve “zero-defect” production.
- To characterize the defect causes in the different Use Cases.
- To define the actions to be carried out in order to actuate on the defect prevention.

The main outcome of this first stage was the definition of the requirements and characterisation of the defect causes of the current manufacturing processes that will be applied to the three specific MuProD Application Domains.

After the collection of data, the MuProD Consortium has tackled the following activities:

- To define the requirements for the MuProD proactive quality control system to be developed:

    1. Requirements associated to the intelligent and synergetic sensors.
    2. Requirements associated to in-process inspection techniques.
    3. Requirements for the Information Sharing Platform.
    4. Requirements associated to the data fusion models.
    5. Requirements associated to the simulation models for prognosis.
    6. Requirements associated to the sensorized intelligent fixturing.

7. Requirements associated to the integrative systems for proactive quality control.
8. Requirements for the feed-back control systems.

- To specify the hardware systems to be developed.
- To specify the software interfaces for connecting individual models and new technical solutions, covering also the programming languages, software engineering methodologies and software tools for developing collaborative working environments.
- To define the specifications for the information models that are underlying in the MuProD Information Sharing Platform.
- To define the normative and standards that the MuProD Project will adopt and extend in the technical Workpackages when building software and generating the different prognosis models.

This activity supposed the basis for sharing different technological points of view and for reaching common understandings within the consortium about the MuProD concept.

Finally, in the future, the MuProD concept of a proactive quality control solution will be applied to innovative industrial scenarios, which are not covered by the three application domains (AD) within this project. Thus, the European industry will develop zero defect production chains for industrial manufacturing end users that will go far beyond enhancing the performance and productivity of current production systems. In order to reach these goals two major subtasks were completed in Task 1.3.

The first one dealt with implementing the MuProD system into other industrial scenarios. Therefore, it was necessary to define characteristics and features of a generic MuProD solution with a universal architecture. By analyzing the three AD their common elements were used to define the structure for a generic AD, which is able to describe all industrial production systems. Basically, it was about creating a template for AD and using this template as basis for a universal MuProD system.

WP 2: Synergetic sensor systems and techniques for innovative in-process data gathering

In this WP the requirements of the synergetic and intelligent sensors for process signal or product data gathering for the three Application Domains were defined. The gaps in terms of sensor and data gathering process to meet zero defect manufacturing in the processes considered have been identified and the appropriate inspection techniques and sensors have been developed, tested and selected. Finally, a new software tool (namely the **Information Sharing Platform** (ISP))for efficiently collecting, distributing, processing, compressing and archiving the huge amount of data collected in real-time by the MuProD process signals and metrology data gathering system was developed.

WP3: Process/machine models for monitoring and adjustment

In this WP Monitoring and prognosis model have been developed. These models are based on data from product, process, fixture and machine and they will allow to prevent defective part generation through efficient operation planning, inline process monitoring and proactive control. In detail,

- Innovative techniques for integrating multi-scale, multi-resolution data provided by different sensors (coming from the WP2) have been developed.

- New tools have been developed in order to reconstruct the geometry of the machined surface and to combine this model of the machined surface with control charting to quickly react to unwanted changes of the machining process.
- Multibody models have been developed including the interaction until the mechanical behavior and the control algorithms in order to obtain the required fixture.
- A mechanistic model and some experimental analysis have been developed in order to get the cutting coefficients characterization.
- Modeling tools and sample models that would later be used (in WP5) as the basis for the proposed test-generation methodology has been developed.
- A proactive control strategy has been developed consisting of process-signal-based and workpiece-signal-based controllers which keep the process stable and the workpiece feature within certain tolerances.
- A methodology to analyze the R&M performances of a complex system taking into account also ageing effects have been defined in this task. This methodology has been applied and validated on a selected case study; in particular the AD3 has been selected as the most suitable for the purpose.

WP4: Intelligent Fixture

All the tasks of this WP4 had two different focuses that have been analysed independently: large parts and small thin-walled parts.

Large parts

In this task, the activity was focused on the Application Domain (AD) 2, the industrial case of GAMESA and two different adaptive fixtures have been developed, taking into account the different phases of the machining process. Each of the fixtures includes some active elements which will help to adjust the part related to the machine. Moreover, with some control algorithms, these active elements acted properly in order to adjust the workpiece with the required tolerances.

Small thin-walled parts

The mechanical and mechatronic design of the active clamping devices (with PZT actuators inside) and of the fixturing system prototype has been completed. FEA model and analysis, together with a preliminary mechatronic simulation have been carried out to prove the systems against mechanical requirements (stiffness, frequency, strength,).

WP5: Development of new integrative solutions for proactive quality control in correlated multi-stage systems

Task 5.1: Correlation Analyser: modelling quality correlation in consecutive process stages.

In this task a tool which is able to analyze the correlation between deviations of a workpiece feature for different process stages of the production system has been developed.

The most suitable tool identified for quantifying those relationships is the cross correlation function from stochastic mathematical theory. It is a powerful method which allows identifying similar behavior in two signals and it is easy to implement and requires few computational effort at the same time. A special case of the cross correlation function is derived for calculating the correlation index. This value is obtained for each pair of measured signals and can be displayed in the correlation index matrix. In that way, it is possible to illustrate the correlations of all measured signals within a production system or sub-system in just one matrix. The calculation of the correlation index and consequently of the correlation matrix has been implemented in Matlab as a GUI application, which is able to analyze data collected in the MuProD data structure. This software is called ‘Correlation Analyzer Tool’.

As a result, it can be noted that the proposed correlation analyzer is a general tool and set of methods that can be applied to very different and even to currently unknown future industrial scenarios and production systems.

Task 5.2: Process-Chain Analyzer: integrated quality and production logistics model of the correlated multi-stage manufacturing / assembly system.

In this task an integrated method for capturing the dynamics of the workpiece flow in order to predict its performance measures in the fields of workpiece quality, production logistics and economics has been developed. One output of Task 5.1, namely the quality correlation structure between consecutive process stages, forms part of seven parameters and variables that have been considered as inputs of the model derived in Task 5.2. The other six factors are the duration of each process stage, reliability and maintainability models, the entity of time and/or part buffers, inspection times and efforts, quality control feedback information flows and costs.
The accuracy of the analytical methods developed for the Process Chain Analyzer in Task 5.2 has been certified in Task 5.3 by integrated model validation and testing.

Task 5.3: *Integrated Model Validation and Testing*

The methodology and requirements from its supporting tools were defined in WP1, the testing-knowledge ontology on which the tool is based was developed in WP3 and the expert system itself was implemented and tested in this task.

The methodology includes several adaptations of techniques that have been successfully used in the general domain of Verification, Validation, and Testing of Engineered Systems. The testing tools have not been used before in the domain of production process testing, and we have shown that their success in simulation based hardware could be repeated here as well. The model-based aspect of the technology has been developed and in task 3.5. Here we focused on the test generation process itself.

The test generator's objective is to perform system level functional testing. This mainly focuses on testing the integration of components that are presumed to have been already independently tested. The approach taken for this is transaction-based testing – i.e. the testing of the production system by simulating "orchestrated" scenarios that each involves multiple components in the production system. The test generator generates large numbers of such system transactions. In general this is done with random generation – but the random distribution of the transaction properties is biased by the tool's internal testing-knowledge and can be controlled by the user through test-templates.

These test templates are written with a language designed for test specification which is automatically adapted to the terminology of the system-under-test through the testing-knowledge ontology.

The test template is one of several sources of *constraints* that the test generator must conform with. Other sources include the testing knowledge in the ontology and the requirements coming from the system architecture itself. The core technology used by the test generator is constraint-programming which enables it to model and solve large constraint problems as can be expected in the test generation task.

The methodology has been integrated and developed for the ENKI use case.

Task 5.4: Production /Inspection Planner: Service level compliant integrated production /inspection allocation and planning

The goal of this task was to develop a package that assists decision making for the allocation and configuration of inspection machines in a manufacturing system where both production and inspection machines interact for the quality control of parts. The dynamics of the production logistics and quality are taken into consideration in the development of a systematic methodology for production/inspection planning. This aims to improve the current industrial practices where similar decisions are often made based on rule of thumb. For this purpose a framework that can communicates with other packages in MuProD to perform a quantitative analysis of optimal inspection planning tools is developed.

Task 5.5: *System Level Defect Manager*

The main goal of this task was to develop a general framework for the integrated analysis of a production system by considering the impact of a system level policy on both the production logistics and quality performances. The package includes different modules that enable this objective. These interoperating functional modules are the definition and representation of system level defect manager based on individual stage level policy, and the adaptation of Process Chain models to characterize the system policy and quality control configurator. In order to optimize a system, this package of modules iteratively invokes the Process Chain Analyzer, which was developed in Task 5.2, and analyzes the impact of alternative quality management action policies. This analysis aims to evaluate different configurations including both assembly stages, processing stages as well as inspection stages dedicated to the measurement of product features under feasible and alternative defect management policies. The overall goal of the framework is to optimize these alternative solutions and reach a system level optimal policy for a given production system.

Task 5.6: *Set-up Manager*

The main goal of this task was to develop a robust production scheduling method in order to handle sequence dependent set-ups with the objective of minimizing makespan or tardiness. The developed algorithm is related to a robust production scheduling method that should preserve its feasibility upon verification of unexpected disturbances, unexpected processing time and unexpected setup times, that are common in complex, time consuming, multi-stage production processes. The technique that is adopted is a simulated annealing algorithm programming that enables including inherently uncertain characteristics of the production scheduling problem within the problem formulation.

WP6: New process-chain oriented workpiece repair solutions for zero defect propagation

Task 6.1: Defect Classification in View of their Management

The main goal of this task was to develop a classification method and framework for the detected defects in view of the possible actions for their effective management. This framework considers as possible options the following alternative scenarios:

- no intervention,
- scrapping and
- workpiece repair.

A first evaluation schema between these alternatives was proposed that compares these actions considering as criteria the impact on the process-chain logistics, the value of cumulated processing, the workpiece value and possible damage risks for downstream equipment. A tool to compare and rank the options was developed in Matlab. The defect types identified in the three ADs were mapped according to the developed framework considering the specific technical feasibility issues of the different actions.

Task 6.2: Evaluation of alternative methods to repair defective workpieces

According to the MuProD approach, several defect management actions are possible if a defective workpiece is identified: no reaction, scrapping, inline rework and downstream repair. Each one of these alternatives has an influence on parameters of the workpiece and multistage production system, like the workpiece cost, the rework duration, the rework cost any many more. In this task, a cost function taking into account all of those parameters was developed in order to solve a minimization problem that identifies the best rework option possible (smallest cost value of all alternatives). As the number of alternative rework operations is known, the global minimum and therefore a global optimum can be found. After applying the identified rework operation to the plant, a parameter adjustment of the cost function weights is done. Within this task, a prototype version of the software performing the steps described above was implemented in Matlab. The prototype uses defect lists identified in the three AD in Task 6.1.

Task 6.3: Defect repair through proactive parameter adjustment at the downstream stages

The main goal of this task was to develop a method for downstream deviation compensation. The Enki case was not suitable for this kind of defect management policy as the tubes cannot be repaired. In case of Gamesa, the cross correlation analyzer showed that there are no significant correlations present between different process stages, so that downstream repair was applied only to the Bosch AD. As deviations in the magnetic field of single rotor stacks were created in the previous process stages (upstream) by the magnetization process and the stack properties, the goal was to compensate those deviations by applying an optimal strategy in the downstream assembly stage, where SP laminated steel stacks are assembled to form one rotor. Two possible downstream compensation methods were investigated in detail for the electric drives production, namely sequential assembly and selective assembly.

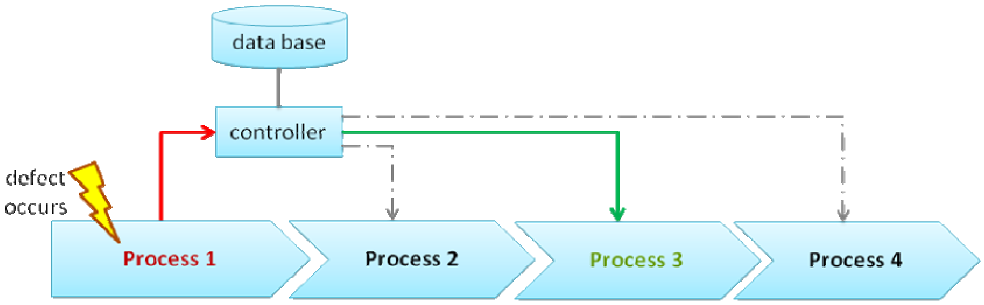


*Figure 2: Basic principle of downstream compensation***.**

Task 6.4: Proactive control for instantly reworking of workpieces in the present clamping

This task aimed at developing methods for repairing defective workpieces clamped in the current process stage. It was based on the production system analysis and defect analysis done in previous tasks and work packages. The main idea of inline rework is that both, inspection and correction take place in the same process stage. The prerequisite of this is that the relevant workpiece feature can be measured and corrected in the current process stage. This restricts the choice of possible processes in the three AD. The main focus of this task was on AD1 and AD2 as no repair is possible in AD3. The tubes produced by Enki cannot be corrected if deviations in the geometry or material properties are detected. The only feasible reaction to deviations is scrapping the tube.

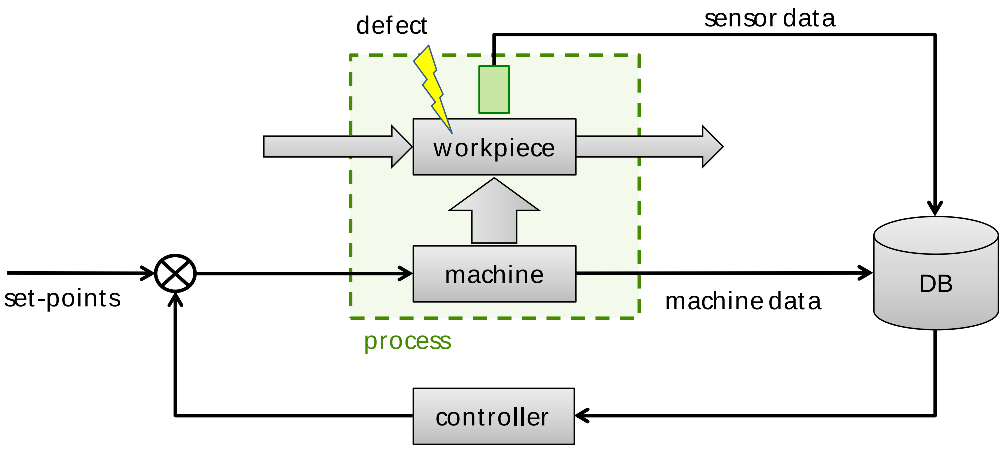


Figure 3*: Inline rework means that the defect is detected and corrected in the same process stage.*

WP7: Demonstration and field testing

The objective of the demonstration activities has been to validate the technological solutions gathered in WP2 to WP6, integrating the technological developments into the three Industrial cases. Since the 3 industrial pilots showed different characteristics, the way that each development has been implemented has been different, but it has proven the Approach to Zero Defect Manufacturing by applied research.

Task 7.1: Production of electrical drives for electrical cars BOSCH

Improving the material efficiency in the production of electric drives is necessary as the electric automotive sector is growing very fast. In AD1, a method for early defect identification and downstream compensation, which allows defect reduction and consequently waste reduction, is presented. This reduces the waste motor parts (rotor stacks) and decreases the amount of rare earths to be recycled. A new inspection device (the so called demonstrator) was developed that allows a space-resolved in-line inspection of single rotor stacks as well as assembled rotors, in the same inspection station. This inspection device was realized as a demonstrator system. The inspection results were used as input for the downstream compensation methods, selective and sequential rotor assembly. Both methods combine stacks that are out of tolerances in such a way that the final rotor is within the specified limitations. Thus, low quality parts form a high quality assembly without having to scrap stacks and magnets

The MuProD solution in this case has included first of all the development of a new sensorized system to measure the magnetic field of the magnets in order to launch the Downstream Repairing solutions in next stages (***Figure 4***).

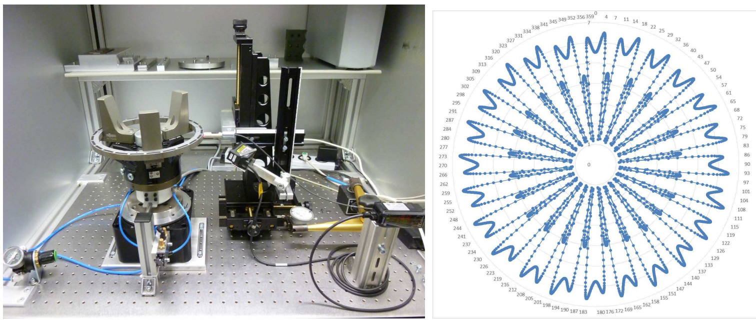


Figure 4: New tests bench and measurements of correct magnetic field in magnets

The downstream compensation identified methods could be summarized as follow: Inline rework of the rotor can be done either by rotating and sorting the stacks or by replacing defective stacks. In both cases space resolved measurements of the magnetic field are necessary.

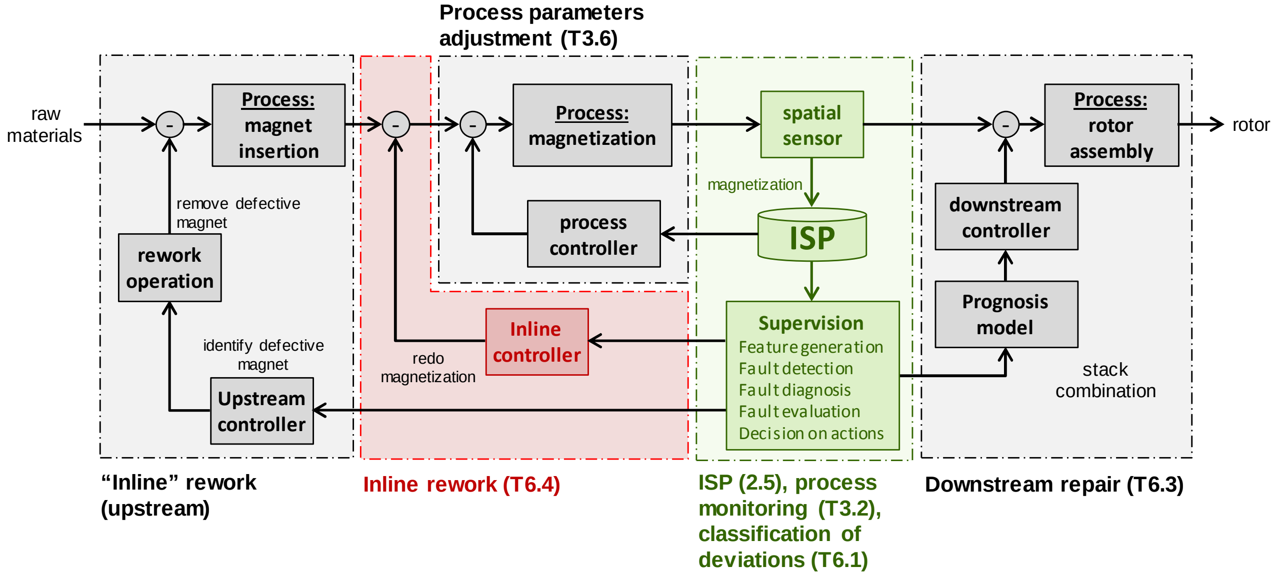


Figure 5: MuProD-controller structure for the magnetization process with corresponding tasks.

Two main strategies were investigated in detail for AD1. The following table gives a short overview about them.

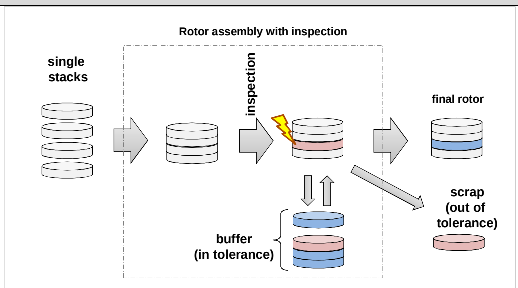
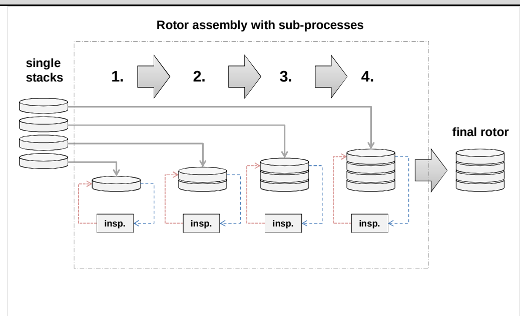
	Strategy 1	Strategy 2
		
Rework effort	Disassembly necessary	No disassembly necessary

Table: Comparison between Strategy 1 and 2

Task 7.2: Demonstrator AD2: Machining line of small-lot production of windmill gear-box large-sized components, GAMESA

Gamesa's application domain corresponds to the manufacturing of small-lot large-parts (i.e. planet carrier) for the gear-box of wind-mills, for the wind power sector. Ever increasing energy demand and the search for "green energy" is leading to the manufacturing of windmill towers able to produce higher power, demanding taller and higher size components requiring new high added value and lighter materials/cast iron. Apart from the current defective production that these high part producing companies might have, the manufacturing of parts made of new materials increases the defective operations and therefore defective parts

The inspection of large-sized parts is a very critical task mainly due to the size and the high amount of geometrical points that shall be measured. At the state of art although some developments have been carried out to inspect the geometry of parts while they are located on the machine, manual measurements are carried out in several critical points of the part in order to control any defective measurement.

This task, presents the AD2 Demonstrator developed at the task 7.2 "AD2: Machining line of small-lot production of windmill gear-box large-sized components", which is one of the three tasks that Work Package 7 - Demonstration and Field testing comprises. Starting from the universal technological advances and digital tools developed in the research tasks, specific software instances and technological solutions have been developed in order to integrate them in the demonstrators of the AD2, to prove the effectiveness of the proposed innovations in the windmill technology industry. The main result is the set-up of a demonstrative production system for the sustainable zero-defect production of large-sized gear-box components operating under the MuProD concept.

This report describes all the work done in task 7.2. The developed technologies that have been validated in the Gamesa industrial case and showed at the demonstrator can be summarized in:

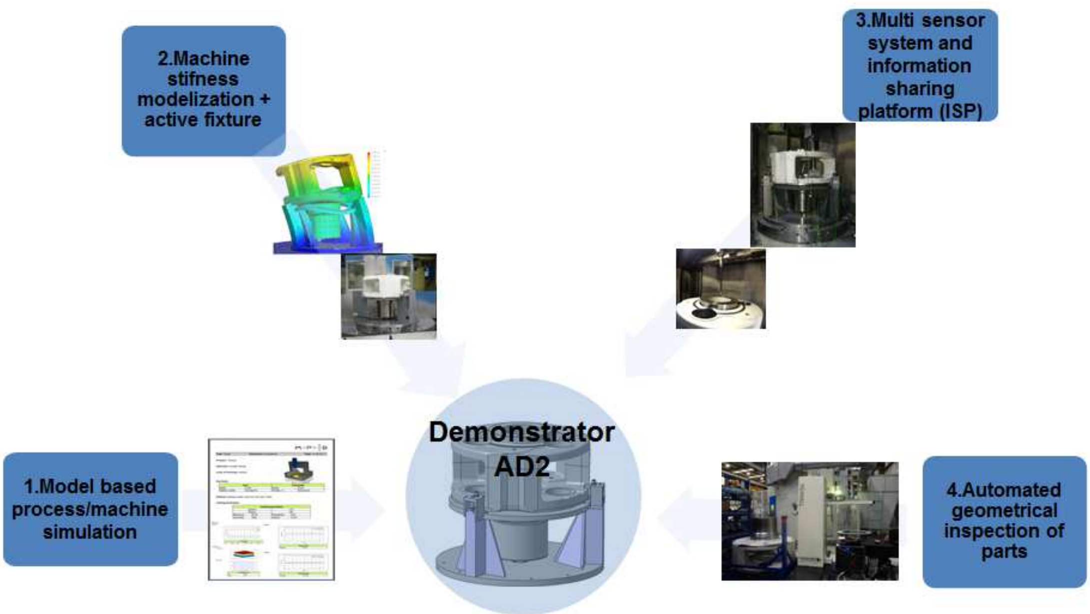


Figure 6: Implementations included in the Task 7.2 in the AD2

Model based process/machine simulation

The main goal with this result has been to develop an advanced integrated simulation models to capture the interactions between the machine and the workpiece in traditional manufacturing processes.

New software, named Dynpro, has been developed within the project. This software integrates advanced mathematical models whose outputs like the cutting forces are obtained immediately only introducing non-complex input parameters like the geometry of the tool or the material of the product.

The main goal of this task has been to develop an advanced integrated simulation models to capture the interactions between the machine and the workpiece in traditional manufacturing processes

To reach these goals, the following activities have been performed in this activity:

- **Identify Operations and Tools for AD2**

Taking into account the operation description provided by Gamesa, critical operations and tools were identified in order to focus the model development on AD2 user case. A brief resume of the most representative operations, tool and materials are presented in the next table.

Materials	GGG70L, ADI900, ADI1000, Others
Operations	External Turning, Boring, Internal Turning, Threading, Milling
Tools	CNMA, CNMG, …, DNMG, RCMT

- **Define the Mechanistic Force Model**

Geometric model and coefficients characterization tests adapted to different materials, tools and operations.

- **Software utility development**

Utility tool for rapid calculation of the output of turning operations: cutting forces, expected maximum and mean roughness, torque and power consumption. Stability analysis.

- **Machine & Tool characterization tests**

The First approach allows to predict and identify deflection as an error source and minimize vibrations analysing machine-tool system.

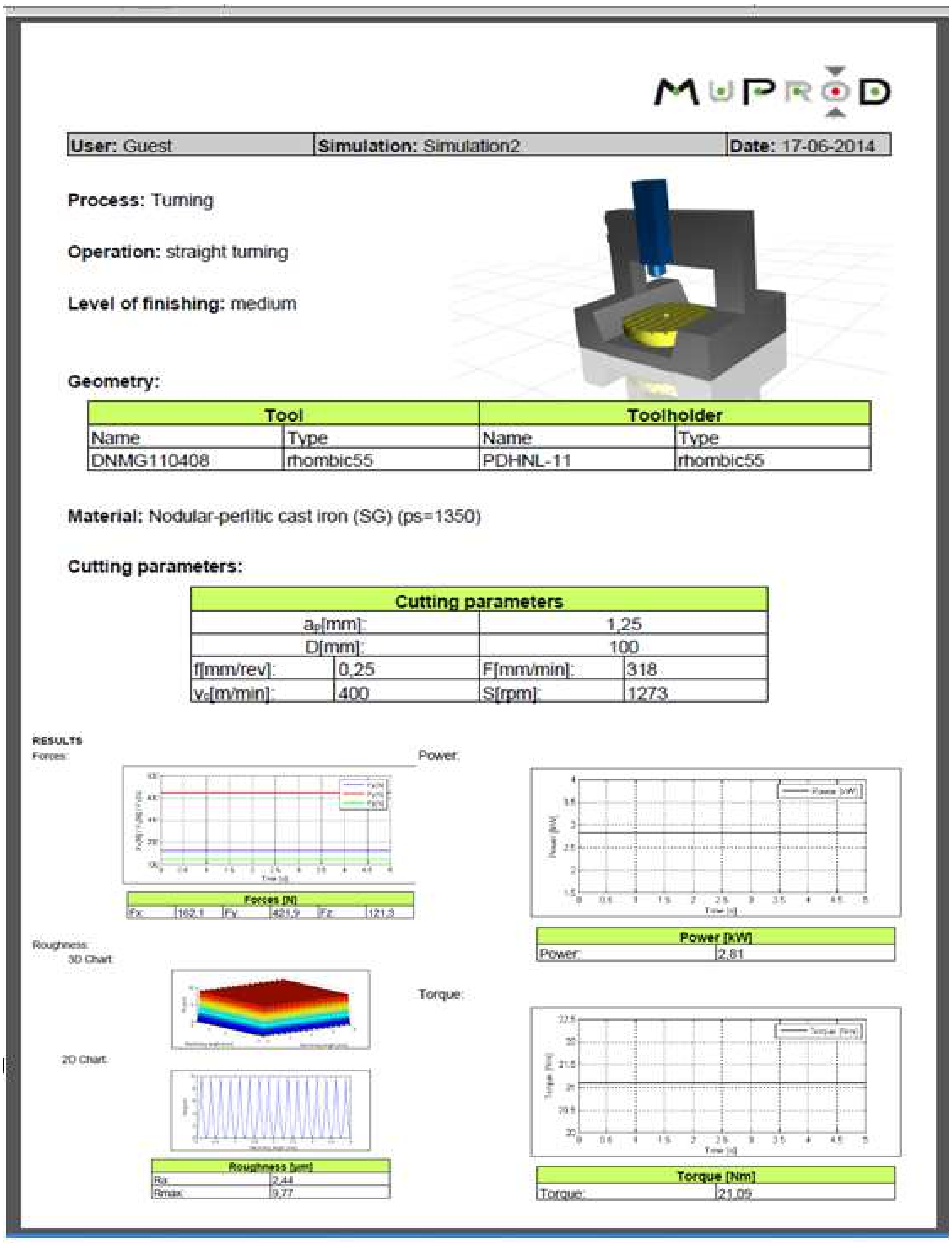
The next section provides guidelines followed during the demonstration in Gamesa. On the one hand the application of the results obtained in Task 3.4 on the development and integration of process models in a real case of Gamesa production system was performed.

In the demonstrator the four modules of the Dynpro software (static, dynamic, deformation monitoring) were validated. The validation steps were:

1. Firstly a simulation of the process is conducted to identify the optimal machining conditions (depth of cut, cutting speed and feed rate for each specific operation). As a result of this

simulation cutting forces during machining will be obtained.

2. Process stability is simulated to evaluate the possibility of chatter in the operation.
3. Deformations caused by the previously simulated cutting forces will be evaluated.
4. The machining operation was conducted following the conditions recommended by DynPro. Cutting forces during machining were evaluated by the monitoring module. If the predictions were not adequate cutting parameters could be modified to obtain a zero defect operation.
5. Finally, by measuring once machined workpiece, it may evaluate the accuracy of the models and the correctness of the predictions. A report is generated by DynPro with the results of the simulations.



User: Guest	**Simulation:** Simulation2	**Date:** 17-06-2014

Process: Turning

Operation: straight turning

Level of finishing: medium

Geometry:

Tool		Toolholder	
Name	Type	Name	Type
DNMG110408	rhombic55	PDHNL-11	rhombic55

Material: Nodular-perlitic cast iron (SG) (ps=1350)

Cutting parameters:

Cutting parameters			
a_p[mm]:		1,25	
D[mm]:		100	
f[mm/rev]:	0,25	F[mm/min]:	318
V_c[m/min]:	400	S[rpm]:	1273

RESULTS

Forces:

Forces [N]					
Fx:	162,1	Fy:	421,9	Fz:	121,3

Power:

Power [kW]	
Power:	2,81

Roughness:

3D Chart

2D Chart

Roughness [µm]	
Ra:	2,44
Rmax:	9,77

Torque:

Torque [Nm]	
Torque:	21,09

Figure7: Example of report obtained by Dynpro solution

Adaptive and smart fixturing system

On the WP4, two different fixtures were designed for the machining process of the planet carrier G8X, depending on the part zone to be machined. This adaptive fixture has been designed for the Phase 2, as it is the most critical one in terms of required tolerances. In this case, the fixture has to center the planet carrier relative to the cutting tool with a maximum diametric run-out of 10µm measured in the central hole of the planet carrier, as it can be seen in the *Figure 8*

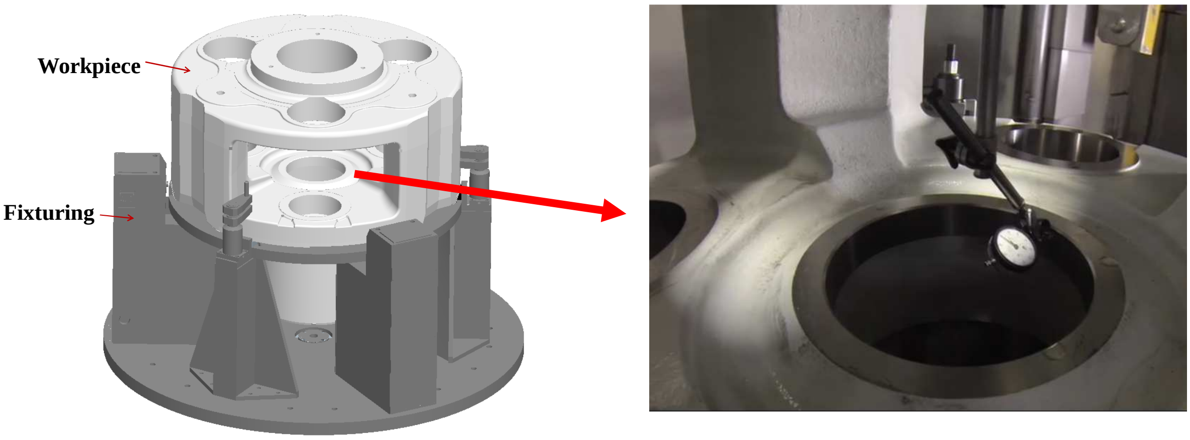


Figure 8: Acceptable run-out of Ø≤10µm for machining in Phase 2

Set-up of the part on the fixture

According with the specifications obtained in previous project tasks the intelligent fixture was manufactured and assembled. Result it is showed on the***Figure9***.

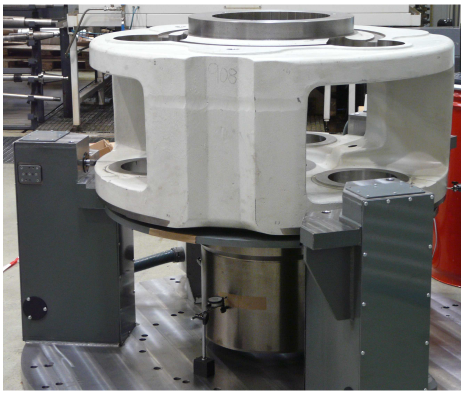


Figure9: Intelligent fixture set-up

It has to be pointed out that part positioning is critical due to the few millimeter gap existing between the actuators and the part. Hence, actuators are retracted to the minimum so a non-desirable contact risk is reduced.

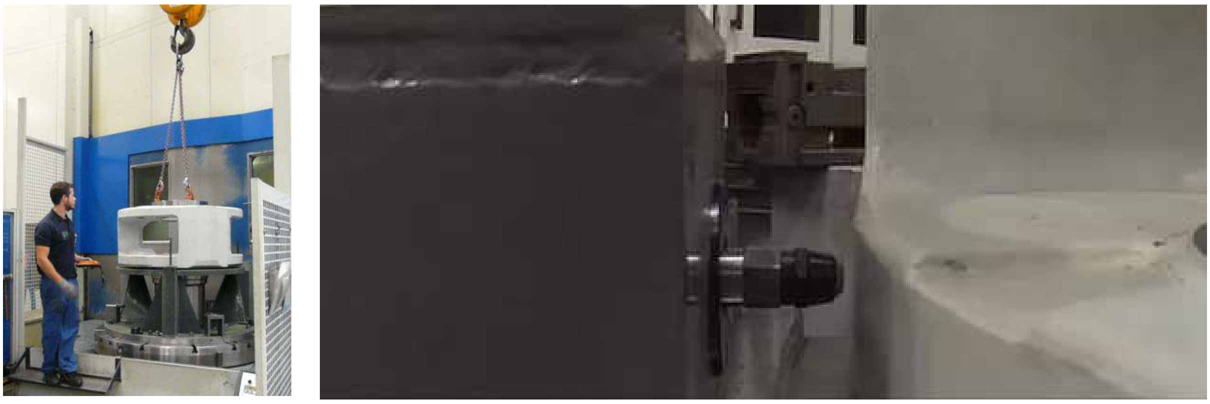


Figure10: Part positioning and the gap between the actuator and the part

Set-up of the fixture on the machine

In the case of Gamesa, the planet carrier G8X is machined on a Pietro Carnaghi vertical lathe with pallet system. Due to the pallet system, one part can be set-up while the other one it is being machined. Then, the pallet would turn around and the other part would be machined.

Figure11: Pallet operation

<u>Demonstration</u>

On the previous task, the three actuators have been evaluated individually. However, in order to center the part, there have to be a movement in the three directions as it can be seen in the diagram of the *Figure 12*

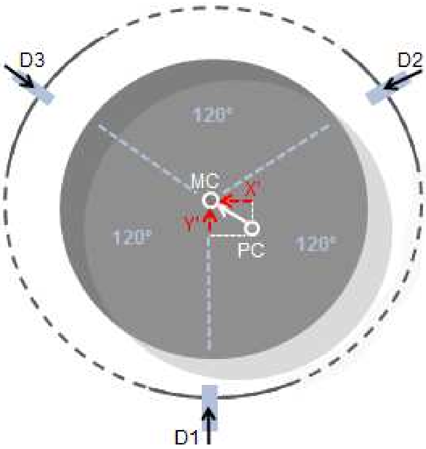


Figure 12: Spindle movement vs part displacement relation

As it can be seen in the previous image, the objective is to move the center of the part (PC) to the machining operation center (MC), with a precision below 10μm. However, it is important to be aware that these equations present the theoretical movement of the part. Thus, these equations simplified the real movements since they do not take into account two physical phenomena:

- Actuators do not applied the displacement force with an exact gap between them of 120º
- There is not just a translation movement of the part, but a rotation as well.

Due to these reasons, in order to obtain a part alignment below ±10μm, an iterative process has to be followed. This alignment iterative process is showed on the diagram of the *Figure13.*

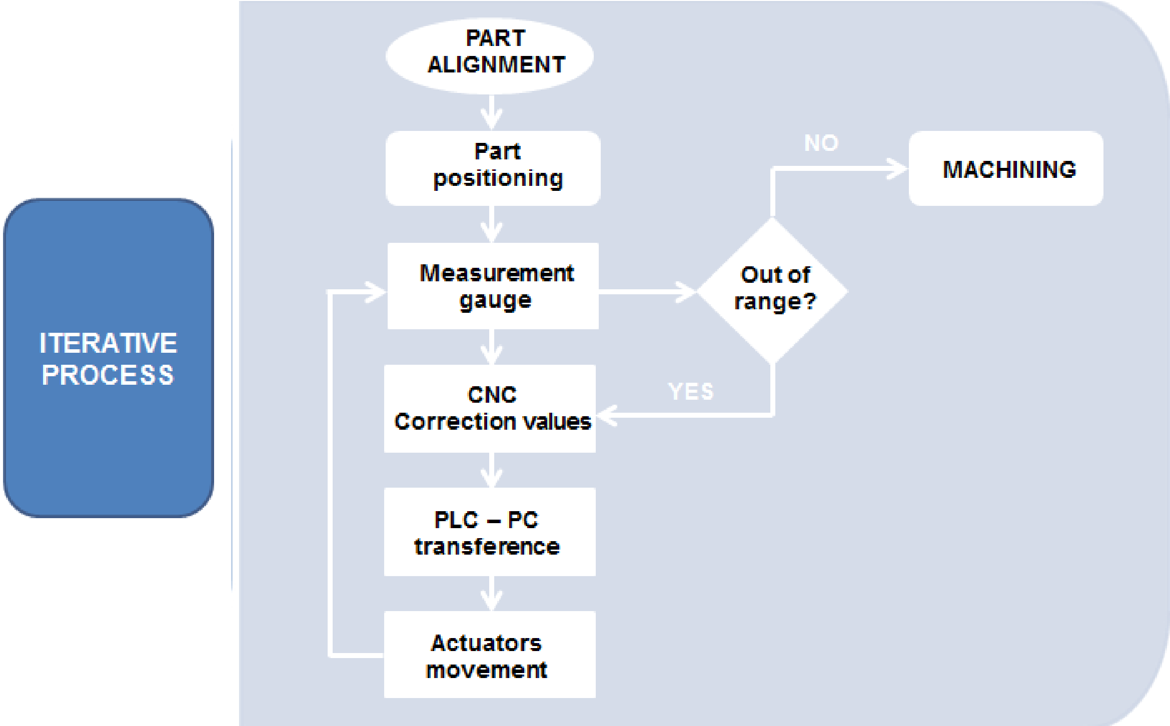


Figure13: Allignement iterative process

<u>Multi sensor system and information sharing platform (ISP)</u>

The monitoring activity has been focused in the deviation from nominal diameter during the boring process of the planet carrier. The use of external sensors (hydrophone, touch probe, dynamic sensor) and internal signals of the machine, have allowed to determine a relation between the tool wear and the features of these signals. These kind of monitoring techniques and diagnostic systems could be a vital way for automation in the future.

In order to efficiently collect, process and store the huge amount of data collected in real-time a new software has been developed, called the Information Sharing Platform. The ISP is a central software tool for collection, storage and analysis of many different measurements and to apply analysis methods on this data. Data sources can be sensor systems, machine controls or other software tools.

As a result, the ISP links together most of the analysis and control tools developed during the MuProD project.

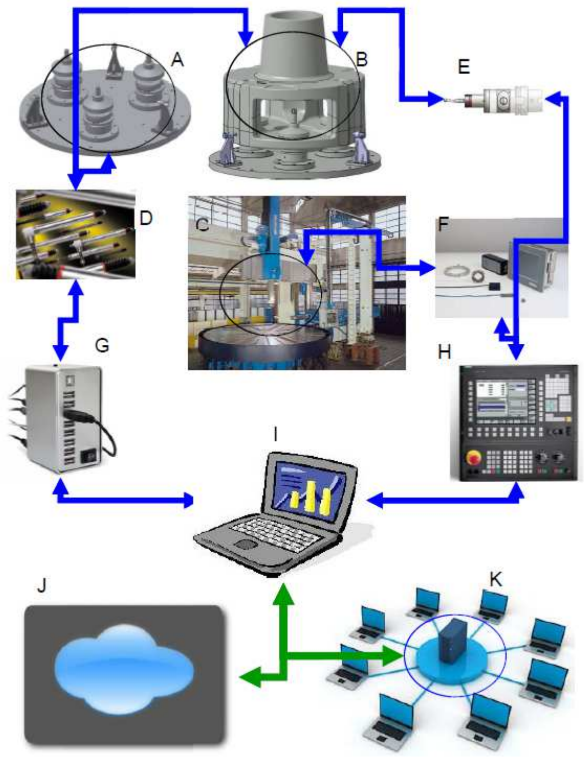


Figure 14: Integration architecture of AD2

In order to select, develop and evaluate the most appropriate sensors, experimental tests have been executed to gather real process and product data in this industrial case.

The experimental tests and specifically the signals and data acquired during their execution have allowed the achievement of these objectives:

· To support the correct election of sensors and inspection techniques.

· To validate the feasibility of sensors and inspection techniques.

· To optimize the process parameters.

· To obtain data for the adjustment and validation of the models to be developed.

<u>Automated geometrical inspection of parts</u>

As it has been told before, the machining process of the planet carrier is divided in two phases, which are due to the change of orientation in the part. Each orientation means one quality control action and one machining operation. Their quality control is divided in automatic or manual. Every beginning of series has an automatic measuring control of each phase, which validates the machine setup. Afterwards every control is done manually by the same technician performing the machining process by means of calipers and manual measuring tools. The efforts in this task have been focused in investigating the improvement and substitution from manual to automatic 100% control.

The measurements have been carried out using Optiscan Hclass model with Trimek's high precision Gantry CMM (coordinate measuring machine). For this task have been performed different test to asses:

- Accuracy
- Repeatability
- Multi resolution

As we explain before there are two types of control, automatic and manual. The first one performs measurements of cylinders, inner and outer and their positions with respect to a general reference. In the case of the manual process it only performs the measurement of the cylinders themselves as the operator doesn't have a general measurement reference as he is using manual tools.

Figure 15: Setup configuration

The main achievements in this task can be summarized in:

- The repeatability of the equipment is 15µm in production environment.
- The tendencies of the measurements results are constant.
- Master part concept is viable
- Possibility for 100% control of phase 1 and phase2

Task 7.3 Demonstrator AD3: Micro-production of micro-intravascular catheters as high value medical products for the aging society

The work conducted in this Task 7.3 focuses on the demonstrator AD3 in terms of their objectives inside the project, its development and, especially, the main results achieved by the consortium.

Within the MuProD project Enki had identified 2 areas of intervention:

1. Active die with 3 control loops
   a. Loop1 control and management of active die
   b. Loop2 dynamic control of parameters during extrusion process using in line geometrical measurements
   c. Loop3 off line manual control of geometry. Possibility to set up manually parameters directly on loop 1
2. In line black spot inspections with cameras

Regarding the first activity, after simulation and engineering of components it was possible to develop the active die.

- Characterization and calibration of thermocouples inserted in the Active die

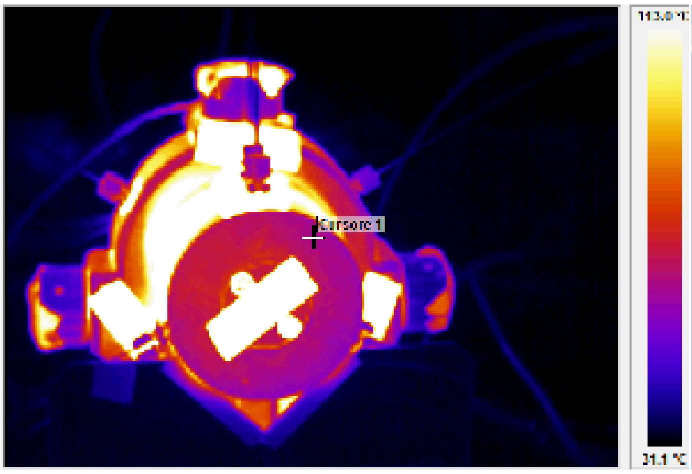


Figure 16: Calibration of the thermocouples

- Off line and in line testing in Enki

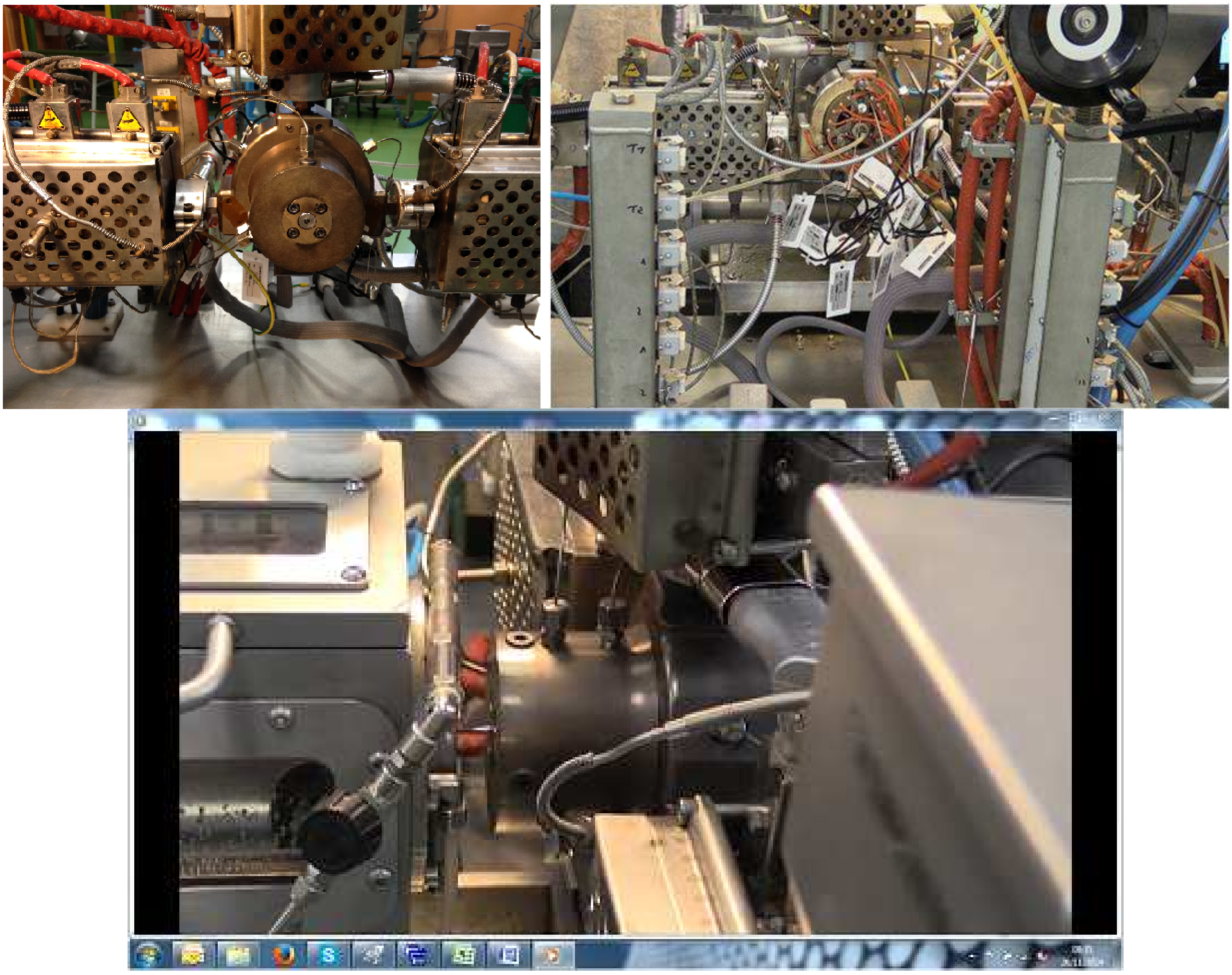
- Engineering and manufacturing of the mechanical parts (pin and die) necessary for the extrusion process

Figure17: Mechanical parts of the active die

- o In-line tests to check mechanical active die functions

Concerning area 2, after analyzing the proposed solution, within the WP7 the trials started, first in the Lab and then in line on the extrusion lines.

- Active die with 3 control loop




0.166
0.186
0.202
0.190
1.471
0.001
0.186
87

Figure 18: Sensorized Muprod active die and the different control loops

The initial tests on the viscosity control carried out with the aid of the active die were not very satisfying therefore within WP6 we further studied this problem and a new solution was advanced. It was decided to develop a smaller pin and die and to plan a new session of trials.

The tests continued within WP7 and the results by the end of the project were excellent.

- Black spots control with cameras

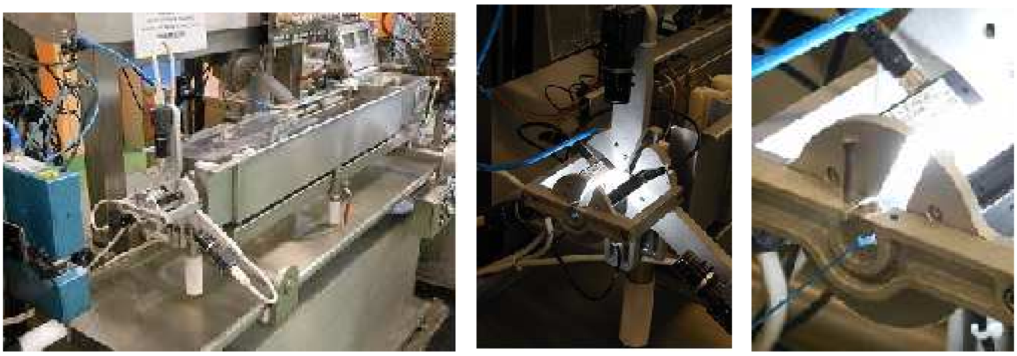


Figure19: Cameras solution – in line test

During WP7 tests carried out highlighted the necessity to implement changes and calibrate the system allowing us to improve the results.
The results hereafter were shown during the last meeting and completed also this second area of intervention.

1) **Materials**: improved knowledge for more efficient tube production
2) **In-line control of black specks and gel:**

Before MuProD

- From 20 to 100% based on quality
  Delayed control (hours or days)
- +100/150% over-production to compensate defective part
- No real-time information

After MuProD

- 100% control
- Real-time control
  Multi-stage System Level: Zero Defect Propagation
- Real-time warning (negative drifts)
  Process Level: Zero Defect Generation

Quality improvement: **30%** Tests and implementations will continue.

3) **In-line viscosity control** by means of the active die:

- No real-time information
- Delayed corrective actions
- Defective production

⇒

- In-line control of the tube thickness
- Possibility to adjust during production

As the main conclusion, it can be highlighted that the results have been very promising and the Enki will be able to improve its finished products quality.

4. Potential impact and the main dissemination activities and Exploitable Results

Potential impact

The main result of the project is the innovative proactive **Quality Control System** that will drastically change the current concept of End Of Line quality control, going beyond currently established methodologies such as Six-sigma and SPC. The involved end-users will be able to implement a "zero-defect manufacturing" solution into their production system at different levels, that is, at one-stage process level as well as at multi-stage production chain, so that MuProD has grouped the Impacts by Application Domains and by production levels:

1) Impacts of MuProD results in the manufacturing line of a mass production line of electrical drives for electrical cars, at different production levels for **European Automotive Industry**.
2) Impacts of MuProD results in the machining line of a small-lot production of large-sized parts for the gear box of windmills, at different production levels for **European Windmill Industry**.
3) Impacts of MuProD results on the micro-machining and micro-extrusion of customized micro-sized catheters, at different production levels for **European Medical Industry.**
4) Environmental and Social Impacts associated to MuProD Project along the manufacturing production processes.

1. Impacts of MuProD results in the manufacturing line of a mass production line of electrical drives for electrical cars, at different production levels for **European Automotive Industry**.

Nowadays 12-15 millions of automobiles with combustion motors are produced in Europe. In the future it is expected that a rising percentage (up to 20% in 2020 world wide) of these automobiles will be sold with electrical power train machines (mild hybrid, strong hybrid, EV). To keep the main adding value within Europe, the industry needs a secured production method for this product which is a new class or product. So far it has never been manufactured in the expected amounts and quality requirements, thus the current manufacturing way is not appropriate for it and therefore new methods have to be developed.

The major manufacturing costs correspond to the cost of materials (copper wire, lamination stack, spindle) while labour costs, energy, etc. are minor. The single manufacturing steps join components to each other into step by step more complex assembled parts. The disassembly process, due to defect production, without material loss becomes very difficult. After the complete manufacturing process, almost nothing can be recycled back into production for reasonable costs.

Therefore, the earlier an error is detected higher amount of material costs are saved. State of the Art is the "End-Of-Line" testing which leads to a big financial and productive loss. Realistically, it can be assumed a production volume of 1.000.000 parts p.a.. Cost estimations show a total loss of 0.5%. Manufacturing cost of each of the electrical machines is about 500€. So, if 80% of the loss can be reduced, then a cost saving of approximately 2Mio€ per year could be achieved. The expected effect is increasing due to the increase in production volumes over the years

2. Impacts of MuProD results in the machining line of a small-lot production of large-sized parts for the gear box of windmills, at different production levels for **European Windmill Industry.**

Today, technical solutions for the sustainable and safe production of large-parts for windmill of a power of 4,5MW in the market. Up to now, the highest power that windmills could produce is 2,5MW. The increasing demand for higher power needs the manufacturing of larger-sized products. Therefore, the use of lighter material is needed and thus new high added value cast iron is demanded. The main drawback of the manufacturing of higher size products made of new material is the complexity of the machining process that causes extremely high product variability and defect rate in the different operations. In this AD, the MuProD consortium will tackle this problem with the proposed technological and methodological innovations and will deliver an integrative quality and process control solution that will stabilize the process enabling the sustainable production of such added value products

3. Impacts of MuProD results on the micro-machining and micro-extrusion of customized micro-sized catheters, at different production levels for **European Medical Industry.**

Today, technical solutions for the sustainable production of micro-catheters with diameters in the order of 0.1-0.2 mm are not available in the market. The smallest micro-catheters that are on the market feature diameters down to 0.5mm and 10µm thickness. The main drawback is the complexity of the process that causes extremely high product variability and defect rate (up to 80% for d=0.2mm). In this AD, the MuProD consortium will tackle this problem with the proposed technological and methodological innovations and will deliver an integrative quality and process control solution that will stabilize the process enabling the sustainable production of such added value products. The impact on the health of the ageing European society will be tremendous, since medical technologies to cure previously uncured diseases will be given to the market. The manufacturing process for producing “one of a kind” customized and single use micro-catheters consists in three main process stages in sequence, two of them dedicated to the production of the customized micro-extrusion die (micro-milling and micro-EDM) and the last operation dedicated to the micro-extrusion of the multi-material multi-layer micro-catheters.

4. **Environmental and Social Impacts** associated to MuProD Project along the manufacturing production processes.

- *Impact on resource reduction:* The integration of MuProD into production chains will reduce the resource consumption in the different manufacturing chains due to:
  - The reduction of defects and therefore defective material;
  - Components will be usable in disassembly process, avoiding material waste generation;
  - The machining process will be optimized, and thus less resources used (cutting tools and coolant).
- *Impact on resource reduction:* Time reduction and resource reduction have a high impact on the energy consumption, so the integration of MuProD solution into production will reduce the energy consumption.

- *Use of alternative energy sources*: The application domains of MuProD project enhance the production and use of “green energy” sources, reducing the “green-house” effects.

- *Impact on life saving and diseases prevention/cure:* The sustainable production of miniaturized micro-catheter will permit to cover the currently uncovered peripherical regions of the human body (40%) where currently uncurable deseases take place (strokes, intracranial aneurism). The treatment of atrial fibrillation (AFib) is an excellent example. AFib is a common phenomenon that is often underestimated. Approximately four to six million Europeans suffer from it; 20% of all strokes result from the condition, which often remains undiagnosed and can increase the risk of a stroke fivefold. Unreported cases of AFib are estimated to be 2.5 percent of the population. Experts believe that as a result of the demographic shift, occurrence of the condition will increase. In addition to the serious physical and emotional aftermath of strokes for the people concerned, the overall economic implications amount to euro 38 billion per year in Europe and lay a heavy burden on the European economy. Micro-catheter ablation therapy can help lead to a significant overall improvement, as well as to a complete cure of the illness. According to recently published figures by the Journal of the American Medical Association, patients who undergo a catheter ablation show significantly less AFib symptoms and enjoy a considerably enhanced quality of.

- *Economics value for the European Society:* According to the study reported by Eucomed, there is a parallelism between the European and US impact concerning the adoption of medical technology for heart attacks cures. According to this study, the change in treatment costs for this disease since 1984 has been 10000 $/year, generating an outcome change of 1 year in life expectancy. Since 1 year increase in life expectancy has a value of 70000 $/year for the society the net benefit of using medical technology for curing heart attacks is 60000$/year; thus, it is well worth to invest in R&D to provide solutions to help curing such diseases.

- *Impact on other sectors*: The 4th of November, an Airbus A380 aircraft had to force its landing after indications of a failure of the No 2 engine. Examination indicated that the engine had sustained an uncontained failure of the Intermediate Pressure (IP) turbine disc, produced by the axial misalignment of an area of counter-boring having produced a localised thinning of the pipe wall on one side that produced fatigue cracking. The zero-defect production or early defect detection would have avoided such a tricky situation. MuProD solution would have avoided it.

Main Dissemination and Exploitation Activities

Dissemination of results has been a key activity for all MuProD partners. Therefore, the MuProD consortium has created a dissemination plan within this Task aimed at maximizing project impact.

The main aim of the awareness and dissemination plan has been to address the following issues:

i. Spreading the project's results to the largest possible concerned audience and targeting stakeholders, such as manufacturing industry providers, researchers, and society in general.
ii. Encouraging different manufacturing sectors to implement MuProD results.

Most of the dissemination and communication work within MuProD has been based on fruitful communication, cooperation and coordination among all partners of the consortium and on interaction with WP8 – Dissemination and Exploitation of MuProD Results.

MuProD dissemination actions were classified into three main categories, according to the exposure level allowed by each category. These categories are:

- Direct communication
- Visibility
- Informative actions

To achieve the dissemination goals of MuProD, each consortium partner made the following contributions:

i. Coordinate publications of MuProD products with WP8 leader.
ii. Share and transfer relevant knowledge to MuProD partners directly and/or through the website.
iii. Initiate workshops and seminars.
iv. Identify relevant conferences for dissemination of MuProD results.
v. Conform to dissemination and exploitation plans.
vi. Propose and encourage student and researcher exchange programs.

The MuProD consortium has been very active in the dissemination activities. For example some of the most important conferences and publications are listed below:

Conferences and Fairs:

- CIRP Conference on Manufacturing Systems, (29th -31st May, 2013) in Setubal(Portugal) where EPFL disseminated his results on the Set-up Manager.
- EMO 2013: (16th -21st of Sept 2013) and 9th International Conference on Stochastic Models of Manufacturing and Service Operations, SMMSO 2013 (may 2013) in Seeon Germany, where Politecnico di Milano took part.
- NAMRC 41st North American Manufacturing Research Conference (10th -14th of June,2013) in Madison (USA) where Politecnico di Milano was invited to show the results in the Task 3.2.
- 3rd International Electric Drives Production Conference IEEE 2013, October 2013 in Nürnberg, Germany where the University of Stuttgart , Bosch and Politecnico di Milano showed the first approach of the results in the Task 7.1.
- Medtec 2013, October 2013 in Italy where ENKI took part.

- Manufuture 2013, October 2013 in Vilnius, Lithuania, where Politecnico di Milano and Tecnalia took part as partner in MuProD and the clúster 4ZDM.
- Manufuture HLG, November 2013 in Mannheim, Germany, where Tecnalia showed the on-going work in the clúster 4ZDM
- Metromeet , March 2014 in BilbaoFair focused in inspection techniques lead by Trimek,
- 4ZDM EU Clúster withing the CIRP 24^{th} Design Conference, April 2014 in Milano, Italy, where Technion, Tecnalia, Bosch, the University of Stuttgart and Politecnico di Milano showed the results in MuProD in the different application domains.

Figure 20:*Angelo Merlo (Mach4), Marcello Colledani (Scientific Coordinator of Muprod) and Ainhoa Gorrotxategi (Coordinator of MuProD)*

<u>List of Publications:</u>

- 5th Manufacturing Engineering Society International Conference in June 2013 in Zaragoza UPV-EHU
- NAMRC 41 - 41th North American Manufacturing Research Conference in Madison, Wisconsin (USA) 10 - 14 June 2013, POLIMI
- 3rd International Electric Drives Production Conference in October 2013 in Nurnberg (Germany), BOSCH, USTUTT and POLIMI
- METROMEET, March 2014 in Bilbao, TRIMEK
- CIRP 24th Design, April 2014 , POLIMI, TECHNION, TECNALIA, BOSCH, USTUTT
- 9th CIRP Conference on Intelligent Computation in Manufacturing Engineering, July 2014 in Naples, USTUTT,

By the other hand, the main objective of the WP8 Task 8.2 was the development of the Technology Exploitation Plan. Exploitation covers the direct and indirect use of the knowledge gained during the project, for creating and marketing products and processes or for creating and providing services after the project ends. So that The Technology Exploitation Plan allows the commercialization of project results, as well as the development of the partner agreements and product refinement issues.
During the project, the partners have worked in the Plan for the Use and Dissemination of Foreground – PUDF -. The final version of the PUDF contains information on:

- Dissemination of foreground
- List of Exploitation results
- Exploitable foreground and its use
- Plan of contingency defined to mitigate the major risks of the project and progress of the actions defined

The **Key Exploitable Result** of the project is the combination of the technological results into a working methodology called "ZERO DEFECT MANUFACTURING METHODOLOGY: ZDM2), described as the Exploitable result nº 1. This methodology could be used for any industrial case and it is the way to help in the exploitation of the corresponding developed solutions depending on the context.

The exploitable results achieved during the project and the potential impact and use of each one is listed below:

Exploitable Results	Potential impact and use
Zero Defect Manufacturing Methodology (ZDM2)	- The consortium has validated the methodology in 3 different scenarios. - It is easy to integrate in any production system. It allows a strong reduction of defective parts increasing the productivity of any production system
Information Sharing Platform	The ISP offers import/export functions in order to fit the needs of different manufacturing systems from a variety of application domains.
Adaptive and smart device for error-free fixtures for small parts	- High precision accuracy of fixtures (no workpiece distortions) - Vibration chatter reduction (high quality machining) - Ease of integration in already commercial machine tools - Strong reduction of machining setup (reduction of throughput time) - Suppression of further machining steps necessary for remedy actions
Intelligent fixtures for large parts	Fixtures designed for specific purposes but also with enough flexibility to be reusable and exploitable to different industrial application
Process monitoring technology based on multi-scale, multi-sensor data fusion for high responsiveness while identifying manufacturing process deviations, applicable to small batch productions	Ability to include data gathered from different sensors with different resolutions and acquisition speeds, such as optical systems, touching probes, etc.
Active die including temperature control for controlling micro-extrusion processes	This new device will provide the possibility to achieve active control of the micro-extrusion process. With this device, a desired material velocity profile along the tube section can be obtained by controlling the temperature in the die sections, which in turn locally affects the material viscosity.
Analytical based software tool for integrated quality/production logistics and economic analysis of multi-stage process chains	Software tool designed for a specific scope, including both a simulation based module and an analytical module for a wide range of applications.
Controller architecture for new process-chain oriented workpiece	This approach contains all steps necessary: classification, decision taking and controlling the

repair solutions for zero defect propagation	reparation process. The controller architecture for repairing defective parts will be interesting for two types of customers: producers of expensive parts and enterprises with mass production systems
Innovative assembling and testing methods for electrical drives.	- Prognosis model for assembling electrical drives - Self-adapting assembling processes - In-process measurement, data processing and process adaption - Reduction of defect parts
LDA (Life Data Analysis), R&M (Reliability and Maintainability) and LCC (Life Cycle Cost) integrated methodologies for repairable machines/system parts	Novel strategic methodology for decision making about maintenance actions management taking care of wear phenomena: a company can limit the investment in internal software and resources asking for the service on demand guaranteeing a high production level (higher rate and quality) thanks to an easy and fast way to assess its reliability.
Micro-machining process modelling tool based on advanced mechanistic models for prediction of forces and workpiece geometry in micro-milling operations.	It is the first tool for predicting forces and work piece geometry in micro-milling processes available on the market
DYNPRO: Utility tool for rapid calculation of the output of turning operations: cutting forces, expected maximum and mean roughness, torque and power consumption.	The utility will use basic but sound information to define the best tool path and program for turning operations, which is of interest for both the machine
A Robust production/setup scheduler	-Effectively handles user-based balancing of two production lines, different product types, sequence-dependent setups and random yield -Quickly generates a realistic production schedule which can be used directly in the shop floor
New methodologies for inline inspection of extruded polymer tubes	These new systems/devices allow: - In-line or off-line inspections on geometrical dimensions.
Improved M3 Multi-sensor, Massive Measurement software suite	Full cloud of point software package

5. Address of public website of MUPROD Project

The URL direction of the MuProD Project website is: http://www.muprod.eu

6. Contact Details for MuProD Consortium

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