Executive Summary:
NANOMICRO project proposes a new process, able to deliver a layer wise manufacturing approach using highly focalised powder/heat fluxes with dimensions in the microns range. This new solution allows to control the spatial resolution within the same limit and building up parts with such extreme precise control of the (fully dense) bulk material build up with control of shape (guaranteed also by proper on-line monitoring systems). The precise deposition system is integrated with a new and breakthrough high productivity concept as result of the investigation of two alternative technical approaches:
b) A single "high deposition speed" laser sintering + microwave preheating head through an innovative "close gun-target"
a) A "multi-parallelized" sintering head concept.
The new NANOMICRO high-precision/high-production (HP2) manufacturing machine is integrated, with
the best working configuration coming from the testing of different feeding solutions, sintering
methodologies (laser and microwaves), uses of innovative nanostructured micropowders and nanofluids,
and the development of a new powerful on-line inspection device able to monitor and to verify the
production quality.

The first level objective of NANOMICRO project is to provide the manufacturing industry with an entirely
new high productive platform for 3D micromanufacturing, by way of a new microns scale resolution and an
innovative “high-precision/high-production” deposition process (HP2 Nanomicro machine). At the end of
the project these features have been achieved for two interesting applications: manufacturing of micro-
parts with volume under 1mm³ and finishing (details size in the 100µm range with 5-10µm resolution) of
bigger micro-parts.

- The second level objective of the proposed work is to extend the microfabrication process capabilities by
encompassing a wider range of innovative materials and geometric shapes, satisfying functional and
technical requirements, allowing the emerging of new microproducts in many technological fields.

Project Context and Objectives:
The layer direct manufacturing technologies to date available (even at lab scale) are limited in space
resolution to about 50 µm in particular for bulk metallic components. Direct, bottom up, fabrication, with
much improved space resolution and productivity could be made available for metallic / ceramic
components. A new process, able to deliver a layer wise manufacturing approach using highly focalised
powder/heat fluxes with dimensions in the microns range, is proposed. This new solution will allow to
control the spatial resolution within the same limit and building up parts with such extreme precise control
of the (fully dense) bulk material build up with control of shape (guaranteed also by proper on-line
monitoring systems). The precise deposition system will be integrated with a new and breakthrough high
productivity concept as result of the investigation of two alternative technical approaches:

a) The “multi-parallelized” sintering head concept using microwaves as heating/sintering tool;
b) The single “high deposition speed” laser sintering head through an innovative “close gun-target”
principle;

The new NANOMICRO high-precision/high-production (HP2) manufacturing machine will be integrated
with the best working configuration coming from the testing of different feeding solutions, sintering
methodologies (laser and microwaves), uses of innovative nanostructured micropowders and nanofluids,
and the development of a new powerful on-line inspection device able to monitor and to verify the
production quality.

Two main objectives are foreseen:
- The first level objective of NANOMICRO project is to provide the manufacturing industry with an entirely
new high productive platform for 3D micromanufacturing, by way of a new microns scale resolution and an
innovative “high-precision/high-production” deposition process (HP2 Nanomicro machine);
- The second level objective of the proposed work is to extend the microfabrication process capabilities by
encompassing a wider range of innovative materials and geometric shapes, satisfying functional and
technical requirements, allowing the emerging of new microproducts in many technological fields;
The S/T objectives for the project are briefly summarized below

- Providing the implementation of highly localized powder fluxes and heating systems to drive high accuracy object fabrication, on the scale of better than 5 um:
  1) High dynamic powder dosing (particle by particle);
  2) In flight particles preheating up to 1200 °C (by microwaves);
  3) Particle acceleration techniques (piezo driven, gas stream, magnetic field);
  4) Laser beam shaping (hollow cone, focus diameter < 5 um).

- Providing deposition strategies and online process and production quality monitoring approaches allowing combinations of accuracy and productivity to be achieved for volumes, part sizes and production rates at which the technology will be a candidate for becoming a new production tool, by realizing a real Micromanufacturing platform for 3D metal parts integrating nanostructures.

- Development of several powder grades as aggregates of nanocrystals, selected in the 5 microns range, and phase assemblies resolved within each (agglomerated) particle, down to a scale of 20-30 nm or so, for NANOMICRO

- Using methodologies for integrated materials and component ecodesign.

- Multimaterial (gradient) deposition using different powder types on the same layer.

- Establishing deep and affordable nano(micro)manufacturing principles by allowing integration of nanoscale structures first at powder level (microns aggregates) and then at 3D part level (mm).

- Integrate above principles in a HP2 microfabrication station capable of delivering 3 parts (typically below 1x1 mm each) in the same workload and/or producing 1 single part using a higher deposition speed head (close “gun-target” principle), both with spatial resolution better then 5 microns using aggregated nanomaterials.

- Demonstrate the viability of the new manufacturing technique in products area like: sensors/actuators (MEMS, MOEMS), telecommunication and medical application fields.

- NANOMICRO machine available for exploitation primarily in the EU manufact. industry.

The miniaturization of a wide large number of sensors and actuators is limited by the availability of micromechanical parts on the market, and by the parts material properties. The main actual limitation to the miniaturization of this type of applications is that the reduction of dimension will affect the final performances. According to this limitation, the development of a new micromanufacturing process that can produce tailor-made micro parts enhanced on dimension resolution and material properties can provide the manufacturing industry with a new solution.

In this proposal we present as example two different applications scenarios that can be produced thanks
to the introduction of new tailor made micromechanical parts:

1) The back ground suppressor proximity sensor “BGS” is based on the optical triangulation physic principle. The designed innovation is the optical system miniaturization, that will lead to miniaturize the sensor dimensions, without penalize the performance and it will allow to adjust the sensor with a micro-actuator from a remote control.

2) (Telemaq) Pulmonary route drug delivery is a very promising way for systemic or chronic obstructive pulmonary diseases treatments: a pocket size, electronic controlled, effective aerosol generator is proposed. This application requires millimetric mechanical structures, very homogeneous metallic material (against damping effect for 50 to 300 kHz operating frequency), mini bonding or welding procedures (electroformed membrane on mini metallic structure) at a very low cost.

Project Results:
(1) MATERIAL DEVELOPMENT - DESIGN
IMAGE: 1-PUBLISHABLE.PNG

On the basis of the two different selected application defined by Datalogic and Telemaq within the nanomicro project and taking into account the performance requirement defined by the end users in respect of the physical, mechanical, thermal and chemical properties the Nanomicro components Granta Design performed an initial rational material selection, starting from the Granta Material Universe database, conning approximately 3000 different materials, to determine the materials most likely to be appropriate for the five end user applications.

In brief the materials selected for the two end-user case studies were AISI410 and AISI316L. In the case of the Telemaq case study AISI316 was the preferred solution. Reinforcement with other materials was considered undesirable as this might detrimentally impact pun the vibrational response sought by Telemaq. In the case of the Datalogic case study, reinforcement with Alumina was considered likely to yield benefits in terms of mechanical and wear resistance performance.

The model developed by UCAM has been implemented in the Granta CES Hybrid Synthesizer. These models have been applied using data from the Granta Materials Universe to indicate a range of potential material combination for production, which are considered likely to match the criteria of the end users.

For both case studies the impact of any porosity resulting from the deposition of the material is likely to be significant and appropriate production steps has been taken to minimize this.

Porosity might in some instances be offset by gains resulting from the reinforcement of addition of carbon.

Models developed by UCAM for assessing material property changes resulting from thermal cycling are currently being incorporated into the Granta Hybrid Synthesizer. A pro-forma for gathering the additional data required for the more in-depth eco-audit on the nanomicro process has been supplied to MBN and has been supplemented with additional data regarding the Nanomicro machine.

(2) MATERIAL DEVELOPMENT - PRODUCTION
Powder engineering exploits MBN’s know-how in nanophased-powder production. The overall goal of these kind of activities is to conceive powder in the range <10μm having the best performances in the respective application area. Engineering trough a systematic approach will guarantee to obtain the best results in the list amount of time.

Process development refers to activities related to the powder production. These include not only the milling process itself but also all the post-process operations such as classification and jet-milling to improve the yield of the process in the required particle size range.

High Energy Ball Milling technology was developed in the ’60 for the production (at the beginning) of super alloys strengthen with tiny oxides dispersion (ODS). This process is able to synthesize at solid state (i.e. without passing through the melted state) a great variety of materials with improved performance nanostructure inside and strong interaction between material interphases.

MBN employs this technology through the use of internally developed milling plants able to process materials under the form of aggregated nanostructured powders.

The main purpose for adopting this synthesis and production methodology is to obtain nanostructured powder for additive manufacturing having particle size distribution ranging below 10 microns and small crystals size to improve material properties.

Different materials have been synthesized using different chemistries and structures. Matrix has been chosen on the basis of material design and type of application. Tuning the activation energy delivered by the ball impacts inside the mill is also important to get the right system features.

Suitable Nanomicro nanopowders must be in a well-defined particle size distribution in order to be meet the project target. Particle shape and related rheological properties are also very important for the powder engineering.

To obtain such a sharp particle size distribution a classification post processing has been utilized. Classification is a process to separate powdery, fibrous or granular materials as a function of their settling velocity combined with the influence of particle size, density and shape. In mechanical air classifiers, centrifugal force is added to gravity to separate the particles by size and density within the air stream. Ideally, an air classifier should shift all the particles that are larger than the so called separation or cut point into the coarse (or oversize) fraction and everything below that cut point into the fine fraction. In reality such a precision of cut is impossible (hardly any materials are purely spherical) regardless of the type of classifier and the coarse fraction will always contain some fines and the fines some oversize coarse. Fine tuning by operators coupled with constant analysis of particle size distribution minimizes fines and oversized coarse.

Most of the issues regarding powder engineering have been taken care of. Classification of variants has
been defined to obtain a good yield of fine particles compatible with the additive manufacturing techniques developed in Nanomicro. All the adjustments have been made considering the target requirements given by consortium partners.

Feedbacks on powder processability in Nanomicro test bench gave good responses for most of powders delivered in dry form, metal inks has been tested and but were not in line with the target of the project.

**(3) MATERIAL DEVELOPMENT - CHARACTERIZATION**

IMAGE: 3A-PUBLISHABLE.PNG AND 3B-PUBLISHABLE.PNG

Characterization activities of micro-objects and powder materials have been mainly focused on the morphological and structural characterization using SEM/EDX, XRD, micro-hardness and optical stereo microscopy. Results are correlated with the materials properties and are linked to the process preparation parameters.

In particular SEM and Optical Microscopy has been used to address the development of the micro-manufacturing process following shoulder by shoulder the improvements in the laser sintering process and giving day by day analysis on the sintered track and samples manufactured by the Nanomicro Machine.

The results on XRD analysis are a direct outcome on the properties of the materials used for sintering, AISI316L produced by MBN with its High Energy Ball Milling process.

This powder has been developed in order to meet the target of a particle size distribution limited to max 10µm, the resulted powder is constituted by a flat geometry particle with an average size of 2-4µm and a thickness below 1µm.

Having these characteristics, along with a wide specific volumetric surface of 90 m2/cm3, this powder can be defined as a nanomaterial constituted by aggregates of nanoparticles according to the EC recommendation 2011/696/EU.

The AISI316L nanocrystalline has been chosen for the production of parts for the End-User in the Nanomicro project, Mechanical alloying by High Energy Ball Milling HEBM has been introduced as a top-down approach for producing nanostructures. In HEBM process, the repeated impact of milling balls causes severe plastic deformation of particles readily producing nano-sized microstructure.

Austenite stainless steels are often categorized in two types according to the stability of austenite phase: stable and metastable. Cold working induced by ball milling causes the metastable austenite phase to transform to martensite phase, but it has no effect on the stable austenite phase.

The rate of formation of strain-induced martensite is influenced by existing dislocation structure and can be accelerated, if the initial dislocation density is sufficiently high.

The XRD patterns show the microstructural changes during ball milling process. Only austenite phase is observed in the as-received raw powder but the diffraction peaks intensity of austenite is decreased
significantly in the ball milled sample, and instead, the diffraction peaks of martensite are introduced indicating remarkable formation of martensite phase during ball milling process.

The structure of the metastable austenite is transformed to martensite phase due to the cold working during the process, but the stable austenitic stainless steel is present even after the prolonged milling necessary to obtain the proper amount of particles in the size dimension (<10µm).

The average crystallite size and internal strain of austenite and martensite were calculated by analyzing the X-ray diffraction peak broadening with the Scherrer equation resulting in an average crystal size of 15nm for the milled powder.

The laser sintering process in the Nanomicro Machine is a fast thermal treatment of the powder, which are quickly heated near to or at the melting point and quickly cooled at ambient temperature by the gas stream of the powder itself and by transferring of heat through the sample. This thermal treatment is sufficient to modify the crystal phase distribution and the stress-induced martensite is completely recovered back to the austenite.

Having this nanomaterial a large surface area and a large activation energy due to its metastable structure, the grain size is expected to grow faster during an heat treatment. However in this case the fast sintering process among with the high extent of the dislocation and grain boundaries and defects induced by the HEBM process are limiting the grain growth.

The results show that the average crystal size grows from 15nm to 23-25nm, the final sintered parts are therefore nanostructured. This confirms the validity in using HEBM for the production of the nanostructured sintered parts.

(4) MICRO-MANUFACTURING MACHINE - PRIMARY FEEDING

The primary feeder is based only a simple principle: the powder is stored in a cartridge, which can be filled under inert atmosphere and closed with a cap. When the cartridge is inserted in the primary feeder an automated mechanism remove the cap and push the cartridge vertically to the rotating chamber.

A rotating brush in the chamber take out the powder particles in the cartridge as it is pushed. The cartridge pusher motor works at a speed in the range of 1µm/s. The powder particles removed by the brush are forced by the gas stream to the connecting tube (ø≈1,6mm) forming and aerosol.

The effort has been concentrated in optimizing the whole system for working with very small powder particles. In particular all the rotating chamber, the mass flow controller and the cartridge pusher.

The rotating chamber has been improved with a new internal shape to achieve a better distribution of the finest powder around the chamber, and requiring low gas volume. The chamber has been designed using a new profile that has been realized to achieve the best compromise between the brush and the size of the powder and the quantity used according also low gas volume in order to improve also the powder.
transport to the capillary component.

The mass flow controller has been modified with the help of the supplier in order to achieve volume less than 0.2 l/min or over 7 l/min. The internal gas valve has been substituted with a little one that have the possibility to manage better the control of the low volume gas rate.

Also the internal controller has been reprogrammed to perform a finest and better actuation of the valve.

The cartridge pusher motor, driver and the screw have been redesigned to have bigger power and less speed during the vertical movement of the screw used as pusher. Also the screw is completely new with a finest profile that allows a better vertical movement of the pusher that introduces the powder inside the chamber.

The primary feeder has been integrated in the Nanomicro Machine and is fully controlled by the machine’s software, in the working condition the powder is delivered in a range from 20mg/h (max precision) up to a maximum of 1g/h.

(5) MICRO-MANUFACTURING MACHINE - CAPILLARY FEEDING
IMAGE: 5-PUBLISHABLE.PNG

In the last few years significant progress has been achieved in feeding small quantities of micron-sized powders. Experiments carried out by several authors showed that these powders can be reliably fed through capillaries excited by sonic or ultrasonic vibration applied directly to the capillary or to a fluid surrounding it.

However, as the particle diameter decreases the relative influence of the gravitational force decreases while the importance of particle/particle and particle/surface interaction forces, such as van der Waals and capillarity forces, increases. As a result, particles tend to agglomerate and adhere to the capillary walls preventing steady feeding. There are many aspects that must be considered in the design and operation of the feeding system: hopper design and its conjugation with the capillary; place of installation of the piezoactuators; frequency and amplitude of vibration, etc. so progress in this area is possible only by conjugating experimental investigations and numerical modelling. Taking into account the complexity of the problem it was decided to create a set of computational tools that would allow designing the powder feeder with the minimum time loss in trial-and- errors experiments.

A computational model has been developed to calculate the acceleration required to disaggregate clusters and fluidize particles and performing these calculations for a range of materials and particle sizes. The model include modal analysis of vibrational parts with arbitrary shape and Evans computational model to define powder feeding rate control strategies by controlling the vibration parameters.

Taking into consideration the model results and the integration requirements a coaxial design was proposed for the vibrating powder feeder.

After market search to find potential suppliers of capillaries, piezoactuators, and driving electronics, the
coaxial sonotrode design were agreed with the ultrasonic equipment supplier Hielscher, leading to the final set-up. It has been eventually integrated with the primary feeder by one of its inlets, this geometry was also suitable to be used in laser sintering head being enough compact to fit in the middle of the three lasers and allowing to obtain a sufficient laser incidence angle between 50 and 40 degree.

(6) MICRO-MANUFACTURING MACHINE - POWDER FEEDING FOCUSING VIDEO: 6-PUBLISHABLE.MOV

Focusing of the powder stream on the sintering zone has been investigated and developed. The target of the project was to arrive at a focalization of 10µm, in the range of the laser spot.

To obtain this result two different approaches have been developed and compared: Electrostatic Focusing and Aerodynamic Focusing.

Electrostatic Focusing has been modelled by numerical simulation to understand the potential trajectories of the charged particles and their interaction with an electrical field. Based on this understanding different approaches of models can be designed, calculated and hereby improved.

The explanations based on simulation show that under certain conditions theoretically an electrostatic field is capable to focus charged particles at the required distance to the outlet of a capillary. The explanations illustrate also that the boundary conditions are extremely narrow and that only small variations on flow speed, particle size and pressure lead to complete differing results. Trying to keep those conditions in the demanded range would mean to have a particle distribution of a hundred per cent stability in a micrometer range, same requirement for the velocity having a stability in mm/s range.

A test bench has been realized for the evaluation of the electrostatic focusing, the parameters of the feeding system has been varied in order to obtain a stable particles flow, trying to decrease the gas flow through the glass tube in order to decrease the particles speed since with slow particles the effect of the electrostatic focusing should be more pronounced.

The acquired videos on the powder stream stability and a quantitative analysis on the stream thickness evidenced that the flow is highly unstable; a periodical discharge of the electrostatic field causes the drop of a big quantity of powder. The discharge is facilitated by the metallic particles itself that cause a reduction of the average dielectric strength of the air. Moreover the electrostatic field promotes the presence of a secondary stream of particles. The particles that have a contact with the outer electrode became electrostatically charged and are attracted by the inner electrode causing the formation of the secondary powder stream.

For this reason a fluid-dynamic focusing has been finally adopted. The MicroLS primary feeder has been modified in order to be able to work with a ΔP in the range of 100mbar by adding a proper digital pressure meter. The quartz capillary tube has been purchased with specific design, reported in order to have nozzles specifically dedicated to Nanomicro Machine purpose:

- To not mask the laser beam
- To have adjustable final hole
- To be transparent at microwaves and having high melting point

The advantage of working with very low pressure allows also to un-clog the quartz tube simply by reverting the ΔP for an instant the necessity of remove the tube from its position.

This feature it is very important in the final machine, as it allows to unclog the quartz tube without loosing the collimation of the powder stream with the laser. In the Nanomicro machine an easy and automatic routine to unclog the quartz tube whenever the ΔP rise above the programmed has been implemented.

The fluid dynamic focusing developed is effective in obtaining the 10μm focalization by reducing the stream thickness by ≈70%. The maximum of the focalization is obtained at about 500-600μm from the quartz tip and it is still compatible with the minimum distance of the laser focusing spot.

The stream obtained was stable for hours, any interruption of the stream due to particle clogging is solved by reverting the applied ΔP for some seconds.

The fluid dynamic focusing has been validated for its adoption in the Nanomicro project and it is compatible with both the microwave and laser head. The quartz tubes used are cheaper than the capillaries that have similar dimension and can be unplugged easier.

(7) MICRO-MANUFACTURING MACHINE - LASER SINTERING HEAD

In direct metal deposition processes a laser beam is used in order to apply the power density that is necessary to melt the additives, usually metal or ceramic powders. However, the resolution in commercial laser additive manufacturing (LAM) of micro-parts is limited to a focal diameter of about 50 μm. A smaller focus, and thus a higher resolution, is usually not applicable. High resolutions of the optical system, such as those used in microscope lenses, require a short focal length. But this is not feasible in close proximity to a melting additive mass.

Current laser cladding technologies have limited resolution of about 50 μm. A new solution has been developed within the project “Nanomicro” to improve the spatial resolution. We demonstrate here a new hollow laser sintering concept that allows more efficient laser cladding and manufacturing of highly precise parts in the range of a few microns. The “micro hollow laser beam system” and a deposition system for highly focused metal or ceramic micro-powders are innovative parts within a high precision 3D micro-manufacturing laser cladding platform.

The hollow laser beam has to be focused to a diameter less than 5 μm to reach sufficient shape resolution. The laser sintering head has been designed considering the general requirements for the hollow beam system, including the:

- Achievement of a focus diameter less than or equal to 5 μm;
- Off-axis focusing with maximum amount of beam incidence, on-axis is strictly not allowed due to a device which is fed axially;
Sufficient distance between the optical system and additive mass;

It was important to determine dimension limits, process contaminations and physical conditions of laser focusing. Special attention was given to the issue of focusing. A detailed understanding of the optical parameters that drive the optical system performance is critical in order to produce useful results. Also, it is particularly difficult to prevent contamination of the optical system, especially if the precision optics is not in sufficient distance to the melting zone.

The multi-focus optical system was our system of choice as it best complied with the hollow laser beam concept and Nanomicro requirements. The implemented solution involved three individual lasers. Each Laser was equipped with a precision multi-axis positioner unit and a micro-focus generator.

Three lasers are used to guarantee a directional independence of the melting process. If only one laser was used, it would lead to directional dependence of the melting process. Directional dependence in the implemented optical system was eliminated by symmetrical and concentric arrangement of the focus-generators to each other. The laser source is a fiber laser that has a wavelength of 1070 nm.

The most important factor affecting absorption is the angle of incidence, which had to be as steep as possible. Due to the structural restrictions derived by powder feeding the angle of incidence is limited, during the project the laser head has been progressively refined in order to increase the beam incidence angle up to 60°.

Direct measurements on the laser beam have shown a significant increase of the micro-focus to bigger than 5 μm, if we increased to a higher laser output level.

The laser system realized has a sufficiently large working distance of about 13 mm and depth of focus of about 15 μm. The three focal points are arranged concentrically in a way they met in a common point. A prerequisite for this arrangement was a completely vibration-free construction of the optical system as well as other moving parts of the laser additive micro manufacturing machine, which was conducted as good as possible. The design of the sintering head compensates the effects of room temperature fluctuation on the parts of the optical system.

(8) MICRO-MANUFACTURING MACHINE - MICROWAVE HEATING  
IMAGE: 8-PUBLISHABLE.PNG

Microwave heating is based upon the ability of a material to absorb electromagnetic energy directly and be heated. It is an innovative and unique method that has the ability to process a wide variety of existing materials as well as novel materials that cannot be processed using conventional techniques. Microwave heating also offers the advantage of improving the properties of existing materials that were processed using conventional methods.

Microwave heating possesses several unique characteristics that are different from conventional (convective) heating. The main characteristics of microwave heating include:
Several microwave heating solutions have been studied, even the susceptor solution. This last solution had been dismissed at first because the susceptor material has high temperature inertia and it cannot be switched from high heating to low heating almost instantaneously. Later, we have seen that this is a very interesting option (combined with direct heating) in order to isolate thermally the heated powder and allow the sintering/melting.

The initial cavity design was used to perform the temperature dependent permittivity measurements. It was also a first approach to the metallic powder heating with microwaves.

With the results obtained, other two cavities have been designed. One of them was the classical solution of rectangular waveguide but with a narrower zone in the centre for the sonotrode. Moreover, the use of Argon to enhance the sintering process has been studied.

The critical aspect for the “in flight” microwave radiation is the rate of heating necessary to increase the temperature from room temperature to 1000 – 1200°C in a very short time. For this reason it has been studied a direct microwave application and an alternative one to the direct heating, that is, the use of cylindrical susceptors. Susceptors are ceramic parts that surround the material to be heated. With this indirect approach microwaves heat the susceptor and the susceptor heats the material, in this case the metal powder.

The pre-heating leads to a limited increase of the average crystal size of the nano structured material, from an average of 15 to 25nm. Moreover the fast heating allows the crystal structure to recover the original distribution of phases that are modified and strained during the ball milling process. Due to the partial melting of the particles their initial shape changes form flakes or plates to almost spherical particles partially improving the geological properties of the material.

Despite the susceptor solution seemed to work properly, tests made with the powder feeder were no satisfactory, basically because the on-flight time of powders crossing the cavity were too small for reaching a melting temperature. For this reason Microwave method was used in a pre-heating stage, in order to aid the laser. In that way, the microwaves can produce an intermediate temperature in the powder that can help the laser in the final melting stage.

Manudirect has manufactured the whole machine according to the machine architecture defined and to the final design of all the necessary main components developed by the partners.
The machine has been manufactured taking into account to realize a prototype with an acceptable industrial level in order to achieve the expected stability, performances and reliability. The components realized by other project partners have been integrated for their hardware and software in the machine frame and with all the ancillary systems that provides control of the CNC, the monitoring, the user interface and the sealed sintering chamber.

As a very good result of Nanomicro project, the actual developed technology has optimized micro-manufacturing processes, in order to guarantee the minimum consumption of raw materials, consumables and energy, taking into account the needs to obtain high focalized flow of powder and laser beams.

These considerations indicate that the optimization of micro-manufacturing processes has been a crucial task to guarantee a sustainable diffusion of these innovative technologies. Optimized processes, in fact, can favour a minimum consumption of precious raw materials, and energy and chemicals (mainly Argon). This results have a positive impact on the economic performances and, consequently, on the social benefits deriving from the higher diffusion among people of innovative devices that can improve quality of life.

The sintering chamber has been designed to be completely sealed in argon atmosphere to facilitate the sintering process with AISI3136L (chosen in Nanomicro) as well as titanium or any other alloy.

The possible leakage of argon due to manual operation in the sintering chamber has been limited thanks to the use of gloves, as in standard glove-boxes, and the installation of a small pre-chamber for loading and unloading of the samples.

The improvement of production rate accuracy and object quality have been started with promising results for the resolution and accuracy target, while for the production rate target it will be not possible to reach the expected ones as the planned building volume it’s too big for the achieved resolution.

The software architecture has been designed based on a real time CNC system, able to proper control the sintering process together with the axle’s motion requirements.

The software has been designed as structure at the beginning with the identification of all the main packages and taking into considerations the real time requirements (multitasking demand) with the machine process control requirements.

The pre-processor software is the interface between the slicing and hatching software, the sintering process control, the powder feeder control, the monitoring software, and the CNC controller.

The Machine architecture has defined in detail all the components to be interfaced, their initial characteristics in terms of connectivity, logic control and power supply.

The Operating system and the system reaction time have been defined, in order to achieve the real time performances requested to obtain the expected final resolution (in terms of control). In order to get the maximum efficiency, to keep centralized all the commands-feedback-signals needed to manage the
sintering process in real time and finally to control the working area positioning, a centralized system based on a Numeric Control has been developed (so-called Centralized Computer System CCS).

Part of the CCS are the software package related to the slicing and hatching software that it’s a commercial software package that has been conditioned in order to meet the nanomicro requirements and the interface with the post-processor software.

Nanomicro Machine Parameters - Software controlled:

Oxygen Level: After initial conditioning the Sintering chamber Argon atmosphere can reach an oxygen level of 50ppm.
Axis Vector Speed: XYZ and rotating axis can go up to 1000mm/min the working condition has been fixed around 100mm/min.
Laser Power: Can be adjusted by the software from 0 to 100%. The laser sintering head is equipped with 3 fiber laser, 2W each, with wavelength of 1070nm.
Substrate heating: Sample holder can be heated up to 200-300°C. The moving axes are isolated to avoid any positioning error.
Vibrating feeding drive: Sonotrode vibrating amplitude can be adjusted by the software from 60 to 100%, as well as its duty cycle.
Powder Feeding gas ∆P: In order to obtain a stable powder flow and the desired powder stream focusing, the primary feeding is regulated by ∆P. The ∆P set follow automatically any pressure change in the sintering chamber, in case of clogging it could be regulated between 0,02 and 3 bars in order to unblock the capillary.
Powder Feeding Rate: The primary feeding can deliver up to 0,3 g/sec. For deposition at high precision the primary feeding can be set at 20mg/h.

Nanomicro Machine Parameters - Hardware controlled:

Capillary tip size: Tip size can be defined before starting the manufacturing process, quartz capillary are available range 40-200µm. A focalized powder stream of 10µm is obtained with 40µm nozzle. Test has been done also with 120µm capillary, obtaining a powder stream focalized in 70-80µm.
Laser Focus: Lasers spot dimensions could be adjusted, managing their alignment and their focus. Since the adjustment of laser focus is a manual operation that can be obtained within 30min this parameter can be used for the different process strategies, increasing the sintering spot but decreasing its power.

The nanomicro technology thanks to the resolution goal obtained and also with the impossibility to reach the initial expected building volume rate, can be exploited in several present and future market sectors where the micro-manufacturing process main requirement it’s to build micro object with high resolution. As the realization of new micro objects in various market sectors required the combination of multiple production technologies to build these new products or to add new features, there will be also the necessity to reach an easily customization of the sintering process to the final production process that at the end realize the object.
CASE-ONE: Microelectronics
Microwelding in electronic and micro-electronic sector represent a significant challenge, and a market with very high volume that request the direct implementation of system in production plant, and nanomicro technology can be easily customized according to industrial process already in place.
According to the market scenario, setting as initial values the cost of one machine equal to 280.000,00 Euro, the machine productivity, the single building part total volume in this case 50x50x50 micron, and the indirect costs to implement and to maintain the machine in productions we will reach a productivity of 20 million of pieces per year for a cost of 160k€/year.

CASE-TWO: Biomedical Market
In the biomedical market there are a very wide number of possible applications that can be addressed by Nanomicro Technology. The Micro Fluidic devices family collect inside micro actuators, micro pumps, micro sensors that need the support of mechanical parts directly integrated on lab-chip, and again with the use and the overlap of different manufacturing technologies.
These applications can be also exploited in MEMS and MOEMS industrial sectors has they have the same needs of functionalities and features.
According to the market scenario, setting as initial values the cost of one machine equal to 280.000,00 Euro, the machine productivity, the single building part total volume in this case 500x500x500 micron, and the indirect costs to implement and to maintain the machine in productions we will reach a productivity of 30.000 pieces per year for a cost of 160k€/year.

CASE-THREE: Rapid Prototyping
Rapid prototyping offers other benefits than just a quick turnaround time.
For example, RP defined as the ability to make 3-D objects from computer-aided designs without tooling facilitates modifying or customizing earlier-generation prototypes.
Common RP methods include stereolithography, laminated object manufacturing, selective laser sintering and 3-D inkjet printing. These techniques continue to evolve and produce visual and tactile prototypes suitable for mechanical testing. They are invaluable for converting computer-generated ideas into physical reality, reducing development costs and facilitating communication of product performance requirements.
Often, though, the prototypes produced by RP processes are not made with materials relevant to the final product. This can result in the prototype and final product performing differently.
Nanomicro technology can easily approach the rapid micro-prototyping industrial sector with the aim to support the realization of micro parts till a total volume of 1 mm3 in order to satisfy also productivity in terms of production time required to build a part.
According to the figure reported, setting as initial values the cost of one machine equal to 280.000,00 Euro, the machine productivity, the single building part total volume in this case 1x1x1 mm, and the indirect costs to implement and to maintain the machine in productions we will reach a productivity of 3500 pieces per year for a cost of 160k€/year.

(10) APPLICATION-1 BACKGROUND SUPPRESSOR
“Datalogic Automation” is a worldwide manufacturer of Industrial devices that are meant to satisfy Logistic and Factory Automation applications. The product portfolio includes barcode and RFID Readers, Safety Light Curtains, Measurement Devices, Vision Systems, 2D Imagers and Vision Sensors, Laser Marking
Products, Photo-electric Sensors, Inductive Sensors. Given the involved technologies of the above products, one of the most important and critical competence for R&D of Datalogic is the ability to develop opto-electronic components.

The success key factors of these components are precision, repeatability, quality, miniaturization level and cost. Since conventional manufacturing technologies of the mechanical parts present constraints and obstacles, particularly when development is pushed toward miniaturization, Datalogic is strongly interested in alternative manufacturing processes like the one that will come from the Nano/Micro project.

Background Suppressors (BGS) are photoelectric sensors based on the triangulation principle. They enable the users to precisely control the sensing range to avoid false detection caused by distant but highly reflective objects. Furthermore they allow a smaller black-white differential (i.e. sensing distance depends on the colour of the object).

Miniaturization can be easily reached with an electronic approach, but a mechanical approach would have a lot of benefits like a sharper cut-off range, a better temperature stability and, generally speaking, better performance. Unfortunately an ideal optical approach for Background suppressors would require complex and precise translations of two lenses (the receiver and the emitter lenses) during the setup of the reference distance. Because of the optical characteristics of these devices, the position precision of these lenses is also a non linear function of the selected distance. This makes the precision of the sensing range setup function dependent on the distance itself. Exploiting the new manufacturing possibilities that are arising with the NANO/MICRO project an innovative opto-mechanical device for a new mechanical miniaturized BGS has been designed. The new expected movement of the lens system should give:

- a de-multiplexing and linear mechanical motion of the receiver lens
- a continuous emitter lens focalization in the entire sensing range

Knowledge about the technology itself and new system to build parts for fast prototyping and for low volume applications has been developed. The fast prototyping is today very important since the time is a very critical subject in the nowadays competition. When low volume are concerned the expense to build metal injections moulding with very small parts are totally not convenient and this system allow to handle low quantity with very high working flexibility, a mould can only build the related parts and needs some skills to make it working.

Having the possibility to build the system with a fast and reliable manufacturing process means that the designer can achieve very soon the ideal tuning of the system or see in advance the weak points directly on the applications, increasing the capability to get the final result in the optimal way.

(11) APPLICATION-2 MEDICAL MICRONIZER

The market requirements for micro mechanical parts is very large and is continuously growing thanks to the miniaturization needs rate of component and functionalities in a wide range of applications. One of the stumbling blocks for successful miniaturization and commercialisation of component as micropumps, microvalves, sensors and actuators is the possibility to produce reliable & economic micro mechanical
components.

The miniaturization of sensors and actuators represent nowadays one of the most promising markets, and the possibility to supply micromechanical parts with complex material properties guarantee a secure success factor supporting the radical innovation process on the industry from the products and applications point of view.

To support the above presented scenario, TELEMAQ suggested using the technological capabilities of the Nanomicro project in order to develop an innovative vibratory mesh piezoelectric nebulizer.

The medical nebulizer for drug delivery is based on a micronizer using an electroformed microholes membrane acoustically coupled with a tiny piezoelectric transducer. The technical scope is to conceive a viable, mobile and convivial device and to propose a vibratory mesh piezoelectric inhaler, which should reach 2 μm droplet size, be very compact (size of a cell phone), autonomous (battery), mobile and ergonomic to ease the respect of drug compliance.

Pulmonary route drug delivery is a very promising way for systemic or chronic obstructive pulmonary diseases treatments. TELEMAQ’s project is to propose a very low cost disposable miniature inhaler in order to generate micron size droplets into lung for anti-pain, vaccine or insulin treatments.

This application requires millimetric mechanical structures, very homogeneous metallic material (against damping effect from 50 to 300 kHz operating frequency), mini bonding or welding procedures (electroformed membrane on mini metallic structure) at a very low cost.

After investigations on the state of art and study on liquid behaviour into the inner diameter of the aerosol generator, TELEMAQ fixed the maximum outer and minimum inner diameters acceptable of the miniature geometry. Once those parameters chosen, a series of simulations have been performed to reach an optimized electro mechanical answer.

Then, new designs of the aerosol generator (metallic part, piezoelectric ceramic, micro perforated membrane) and tools (gluing of the piezoelectric ceramic, forming of the membrane) have been followed by supplies and manufacturing.

Bench tests and measurements tools allowed to characterize the structure by measurements and to compare it with simulations performed previously. Moreover, aerosol tests showed that the miniature aerosol head generator works by generating the micro droplets.

Potential Impact:
- Development of an integrated process for micro-production capable to manufacture emerging micro-products, contributing to establish a European nano and micromanufacturing industry;
- Extend the range of microfabrication process capabilities by encompassing a wider and innovative range of materials and geometric forms, and extend the use of nanomaterials in micromanufacturing. Full integration at nano-micro scale would be as well realized, since nanostructure will be retained in the final part;
- Provide significantly higher production rates for small micro-parts (<1mm³ in volume) and finishing (manufacturing of boundary details) of bigger micro-parts, accuracy, and enhanced performance/quality, creating capabilities for the serial manufacture of micro components and/or miniaturised parts incorporating micro/nano features in different materials;
- Answer to functional and technical requirements of new emerging multi-material micro-products in sectors such as telecommunications, medical/surgical, and consumer products;
- Material and processing technologies are ensured of robustness and cost-effectiveness.

Moreover, NANOMICRO will:
- Transfer laboratory processes and solutions into an industrial scale, by making available a 3D parallelized microfabrication station capable of delivering NANOMICRO scale resolution using nanomaterials, in the building up of 3D parts out of metallic and ceramic materials.
- Introduce automatic on-line inspection process to perform production quality control and produced components metrology characterization.

Finally, for the increment of scientific knowledge in the nano-micro scale, NANOMICRO contributes to:
- improve the knowledge in the nanotechnologies field as regards the development of innovative micropowders having nanofeatures;
- develop new design methodologies;
- improve knowledge on system sinterability in the 5 micron-size range;
- improve knowledge on process control and manufacturing precision;
- explore innovative solutions beyond the state of the art in the fields: laser-less sintering systems, ink-jet "like" printing, laser beams, microwaves;
- enhance multidisciplinary knowledge;

List of Websites:

www.nanomicro-project.es

Related documents

final1-pictures-movie-publishable-summary.pdf

Last update: 4 November 2014
Record number: 149779

Permalink: https://cordis.europa.eu/project/id/228815/reporting