



DOCTORAL PROGRAM IN MANUFACTURING AND PRODUCTION SYSTEMS

Chair:
Prof. Bianca Maria Colosimo

Manufacturing is a leading sector of the European economy since European Manufacturing is a dominant force in international trade. As an example, the EU's share of total global manufacturing trade was 18% in 2004, while the US had 12% and Japan 8%." (Manufuture Strategic research Agenda – September 2006 – European Commission).

In some key sectors such as machine-tool, robot, and automation industry, Italy has even achieved a global leadership, accounting for about 10% of the total export (acting as the third in the world) and Lombardia is playing a dominant role, hosting 48.2% of the Italian companies (Report 2005 of the *Association of Italian Manufacturers of Machine Tools, Robots, Automation Systems – Ucima*).

In this competitive scenario, Politecnico di Milano has the fundamental role of providing people with specific training in Manufacturing and Production Systems engineering, by strengthening their research skills in the industrial and academic context. Therefore, the PhD programme in Manufacturing and Production Systems focuses on the optimal transformation of raw materials into final products, addressing all the issues related with the introduction, usage, and evolution of technologies and production systems, during the entire product life cycle.



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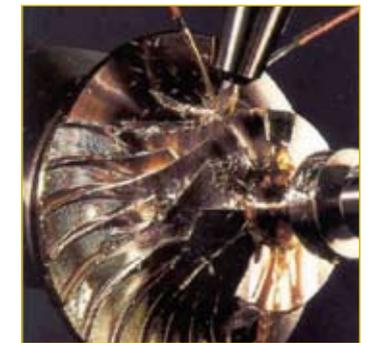
Career Profiles

The professional skills acquired in the degree program give the competence for managing and solving problems related with product and/or service realization. In particular, issues of continuous improvement and integration of all the activities ranging from

conception to realization are emphasized. A Ph.D. in Manufacturing and Production Systems acquires her/his knowledge through the activities of study, research, lab experience, development in cooperation with industries, foreign institutions and international research groups. Using her/his background, the PhD candidate will be able to blend the exactness of scientific knowledge with the ability to deal with practical industrial problems. The outlined skills are of great interest to industrial companies devoted to: i) continuous improvement of technologies and processes; ii) strong integration of product-



2.



3. Manufacturing Processes

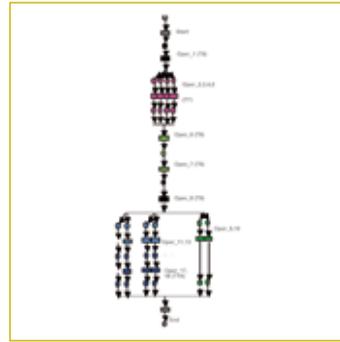
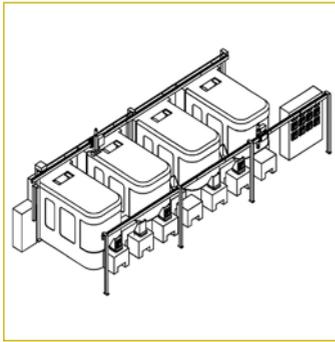
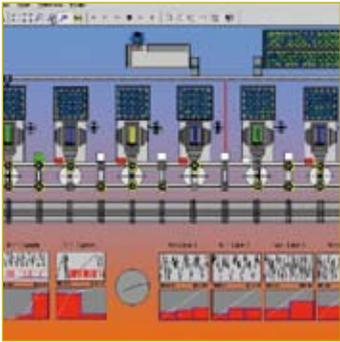
process-system design; iii) complete product lifecycle management; iv) optimal design of production, logistic and service systems. In this view, a Ph.D. in Manufacturing and Production systems can eventually aim at prestigious positions at national and international level within industrial companies, consulting companies, universities and research institutions.

Main Themes

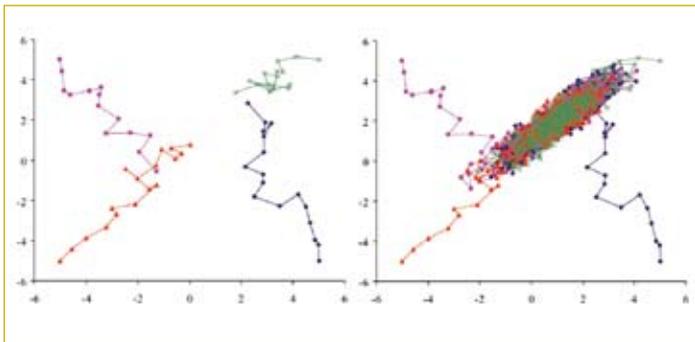
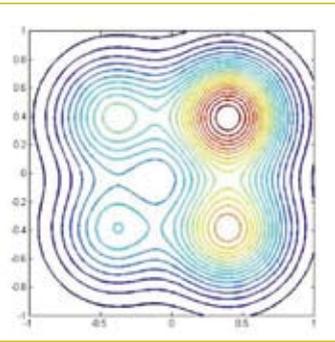
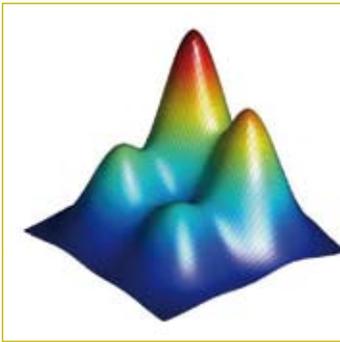
Ph.D. activities can specifically focus on

one of the following topics:

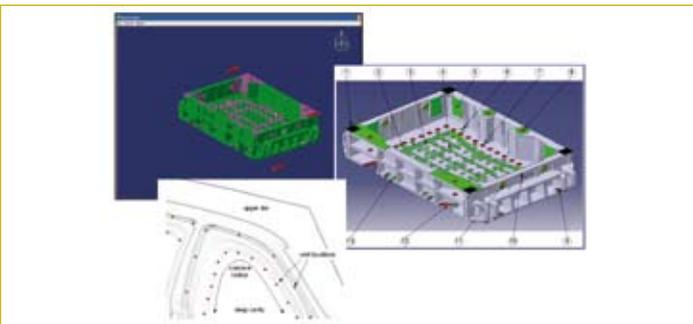
- *Manufacturing Processes (fig.3)*: This research area is aimed at studying both conventional and innovative manufacturing processes. The study can specifically deal with: developing new processes for innovative applications or for innovative materials; evaluating the application constraints of new and existing manufacturing processes; performing economic optimization of the process performances, investigating on the relationship between process parameters



4. Production Systems



5. Quality



6. Product Lifecycle Management

and process results. The research area is therefore very wide, with activities ranging from basic to industrial research.

- *Production Systems (fig.4)*: The research activities carried out in this area are concerned with the design and management of integrated production systems. The research activities encompass innovative and traditional system architectures in different sectors (machine tools manufacturing, production of mechanical components, services). Studies and research activities are based on real cases and underline the deep relations amongst products, processes and production systems.
- *Quality in Manufacturing (fig.5)*: Quality has a relevant role in the new competitive scenario

in which European manufacturing is pushed toward high-value products. Research activities in this area focus on studying and developing new approaches, methods and tools for quality management, process monitoring, control and optimization and metrological issues (design and verification of geometric product specifications).

- *Product Lifecycle Management (PLM) (fig.6)*: This area provides the methodologies and tools related to computer-based product lifecycle management, with emphasis on the automation and integration of product design and process planning. Relevance is also given to the impact of process design on production-system design, both at single-plant level and at network-enterprise level.

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STUDY OF THE BACK TEMPERING PHENOMENON IN LASER HARDENING OF LARGE SURFACES

Anmin Liu

Today's highly competitive markets require the industries to look for new technologies to improve the product performance and productivity. For industrial equipments, most engineering components not only rely on their bulk material properties but also on the design and characteristics of their surfaces. Surfaces are the bounding faces of the solid components; they always interact with the working environment, and under severe conditions their performance and reliability can be limited due to the wear and corrosion. The solution of the problem is surface treatment. Surface engineering involves different special treatments to alter the properties of the surface phase in order to reduce the degradation over time; this makes the surface robust to the environment in which it will be used and prolongs the component life. Laser surface hardening is also called laser transformation hardening or laser hardening. It is a technique to obtain hard and wear resistant surface layer with a typical thickness of 0.5 to 1.5 mm. A laser is as a heat source, scans and heats the surface, the rest of the component acts as a heat sink resulting in a high cooling rate. Laser hardening is a promising process for ferrous family to

produce a hardened layer on the surface. As the laser beam has a limited spot dimension, when the area to be hardened is larger than the laser spot, multiple passes have to be applied, the later track reheats the previous track slightly, due to the less severe thermal cycles undergone by the overlapped area, the existing martensite is transformed into tempered martensite, which characters as lower hardness, this is the well known back tempering problem. The result of overlapping is non-uniform of both hardness and hardening depth in the hardening zone. For planar surface, the effects of laser hardening parameters on the hardened surface were studied. Based on the control system, where the temperature was controlled in the feasibility window, hardened surface can be obtained by different combinations of laser power and scanning speed. The hardness drops in the overlapped zone when a large surface is treated. One solution to the back tempering phenomenon is laser melting. When the surface of the workpiece is melted and solidified rapidly, a new refined structure with high hardness is formed on the top surface, this new structure is not affected by the back tempering in the overlapped zone, and a uniform treated surface could be obtained

by overlapping laser melting process. To get a uniform melted surface on the top surface, high temperature must be guaranteed. The other solution to the back-tempering consists substantially in avoiding the overlapping is making use of very large spots. The spot can be enlarged with a traditional solution by a scanner head, which allows large, shaped spot to be obtained moving the laser beam with high frequency and programmed paths in x and y directions. Laser hardening making use of scanner head permits to cover larger area, even though the industrial experience limits the spot no larger than 100 mm, since the laser power has to be correspondently increased. Thanks to the recent events of high power fiber laser, this limit can be exceeded, and it is time to apply the laser hardening to the large surface in industry. Once the process operability range was investigated and auxiliary equipments, such as pyrometer or thermo cameras to keep the control of the surface temperature, have been optimised for the active fiber laser sources. Under the investigation of scanning a fiber laser beam, the most important two facts are the dimension of the laser beam and scanning frequency. An 8 mm width of hardened layer was obtained



1. Apparent Spot laser hardening



2. Setup of the Apparent Spot laser hardening system



3. Hardened surface by AS technique

on the top surface. For the cylindrical surface, the back tempering phenomenon happens in both single annular track hardening and wider surface hardening, if the cylindrical workpiece is under a low speed rotation during the hardening process. When a single annular track is required, the overlapping exists in

the initial and finishing parts. For a large cylindrical surface, the overlapping happens between the neighbor tracks as it in the planar surface. Apparent Spot (AS) hardening is a new technique to solve the overlapping phenomenon for the cylindrical workpiece. The mechanism of this technique is to rotate the workpiece

at a high speed, and a virtual circular laser spot is obtained around the circumference of the workpiece (Figure 1). When the AS technique is applied to treat a single annular track, the hardened results are depend on the diameter and input energy. When the diameter of the workpiece is too large, the input energy cannot get a fast heating phase. Consequently, the rapid self-quenching is no longer ensured and lower hardness is obtained in the hardened zone. The heat accumulation in the cylindrical workpiece is an important factor which has to be considered during the hardening process for a cylindrical workpiece. To treat a lager surface by AS technique, high power and high feed rate must be applied to reduce the heat accumulation in the bulk material. An apparent spot (AS) was gotten by rotating a cylinder of 15mm diameter at 2100 rpm; a 1200 W diode laser was used to harden the surface of the cylinder (Figure 2). Uniform hardened zones without overlapping were achieved in AISI 1040 steel under different explosion time; the hardness is stable around 600 HV and without drop (Figure 3). The effects of the process parameters (rotation speed, laser power and diameter of the workpiece) on the dimensions and hardness values of the hardened zones were pointed out.

PERSONALIZED PRODUCTION: RECONFIGURABLE TOOLS FOR CUSTOM MANUFACTURING PROCESSES

Marco Cavallaro

The manufacturing globalization has brought a high level of competitions, especially in all the sectors where it is not well defined the monopoly. It has intensified worldwide competition to a level which reduces the earning margins. The mass customization, of course, has tried in the early past to satisfy the major requests of the people, but the next manufacturing paradigm points strongly to a new challenge which could be the personalized production, a manufacturing paradigm able to offer to the final user, their own products which fit perfectly their own needs and wants. Although the mass customization production provides and develops multiple sets of options which can be produced on a mass production system and offered to potential customers with the aim to satisfy the specific needs of many customers; the mass customization does not mean producing an individual product as in the craft production paradigm (one-of-a-kind). In personalized production, customers are actively involved in the design of the products they want to buy (fig. 1). A real and effective personalized production could require a longer production time; the thesis aims at developing a reconfigurable tooling system able to compete with standard

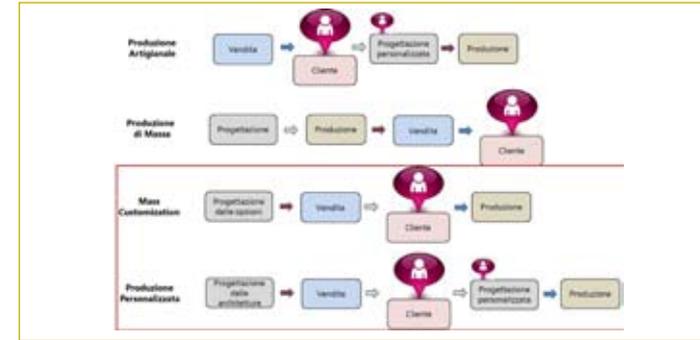
production in terms of time and cost of production and with craft production in terms of flexibility and product functionality.

The real passage from the mass customization to the personalized production (red rectangle in fig. 1) could be difficult since the social influence of the major brands can be really important in innovation and development of the products. For this reason, the case study of the research is focused on lead user markets, the orthopedic and sport equipment fields, where the innovation is generally created and due to the explicit people needs. In these markets people could shift the latent needs of the rest to explicit requests later. This is what happened with the wheelchair, invented by a disabled person or with the roller (inline skate) created by an ice-skating athlete disabled to train during the summer period.

The state of the art is based on different methodologies currently used to produce personal equipment: craft production, additive manufacturing and molding process through subtractive manufacturing of master and molds. The craft production is still the standard process of manufacturing personalized solutions (e.g. most of the orthoses, prosthetics

and customized sport boots are made by hand). The additive manufacturing seems to be a valid alternative for producing personal bone implants, but they are too far in terms of costs and time production to be implemented in an industrial scenario of "personalized" production. The molding process, such as injection molding, thermoforming, resin transfer molding, etc. is a valid alternative to craft production but the related costs are higher and the data treatment from anatomic body capture (personal data) to product manufacturing is really complex. From the scanning information (generally cloud of points), it is necessary to define a 3D anatomic shape, then it is possible to design respectively the product, the mold and the toolpath of the subtractive process. When the mould is ready the mould process will start.

Certainly, the recent technologies based on IT solutions could improve the current state of the art, they can deal and modify the personal data of the final user, such as ergonomic and biomechanical data, necessary for an adequate production. However these technologies do not allow an industrial approach as a new production paradigm: the personalized production



1. The customer role in the different production paradigms

as evolution of the mass customization. These technologies will be too complex and time/cost consuming if they are considered for an individual production. The basic idea of the PhD research was to develop a reconfigurable system, based on pin elements movable along Z axis, able to define a different shape for any individual forming process. The reconfigurable tool could be used for forming, molding or casting of complex curvature parts from metal, polymers and laminated composites.

Most of the reconfigurable pin-type tooling application studies have been focused on forming parts with high length-to-thickness ratios in manufacturing situations where part variety is high, production quantities are low (e.g., aerospace and marine industries, prototyping), and part geometry consists of gentle curvatures. In the current research studies, reconfigurable pin-type tooling offers design and manufacturing flexibility, and obviously potential cost and time savings for product development. It is expensive to produce an individual mold to form any big component for a low quantity of products.

However in these scenarios there is enough time to configure and then use the molds at the same configuration for several forming activities; currently exist different pin actuation methods able to change the shape of the tool by moving pins in and out relative to one another. Different pin actuation methods include, but are not limited to mechanical (e.g., leadscrew-driven), pneumatic, hydraulic, and use of a robotic manipulator.

The main problem is that the reconfiguration time and resolution of the current reconfigurable moulds are not adequate to produce "personalized products" in the case study. The part variety (connected to the individual production) and the production volume are contemporary high (e.g. customized footwear soles). Beside the technical aspect of the mould, other problems have been faced, such as:

- the need of a personalized production in terms of ergonomic and biomechanics reasons;
- the difficulties related to scanning anatomic body districts in terms of neutral position and ability to

- distinguish soft and hard parts (such as bones);
- a software tool able to treat 3D coordinates in order to define rapidly a pin-type tooling 3D shape;
- a way to pass from discrete pin-type tooling surface to continuous and uniform surface;
- the design and the physical prototype of the reconfigurable tool system into a vacuum system in order to perform experimental mold processes;
- the freezing/blocking systems, necessary to use the tool as industrial mold.

The PhD results have allowed to design, prototype and use a dedicated 3D laser scanner to capture the anatomic parts such as feet. The system is able to acquire foot sole shape directly and indirectly using a vacuum cushion able to distinguish hard/soft parts and to reach the right foot position. A MatLab tool was developed to rapidly treat and convert the 3D coordinates of the captured cloud of points to Z quotes of a pins' multitude. A polymeric interpolator was found to uniform the final surface of the mold. A reconfigurable tool mold of about 1000 pins was prototyped into an integrated vacuum system able to process different materials (sheet metal, polymeric, thermoplastics and thermoset composite materials). The reconfiguration methodology has been finally developed and verified, the reconfigurable tool is able to reproduce in a few minutes freeform surfaces, necessary for the personalized production.