MECHANICAL ENGINEERING I PHYSICS I PRESERVATION OF THE ARCHITECTURAL HERITAGE I SPATIAL PLANNING AND URBAN DEVELOPMENT I STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING I TECHNOLOGY AND DESIGN FOR ENVIRONMENT AND BUILDING I TERRITORIAL DESIGN AND GOVERNMENT I URBAN PLANNING, DESIGN AND POLICY I AEROSPACE ENGINEERING I ARCHITECTURAL AND URBAN DESIGN I ARCHITECTURAL COMPOSITION I ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING I ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE I BIOENGINEERING I DESIGN I ELECTRICAL ENGINEERING I ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY I ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING I INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING I INFORMATION TECHNOLOGY I INTERIOR ARCHITECTURE AND DESIGN I MANAGEMENT ENGINEERING I MATERIALS ENGINEERING I MATHEMATICAL MODELS AND METHODS IN ENGINEERING

Chair:
Prof. Bianca M. Colosimo

DOCTORAL PROGRAM IN MECHANICAL ENGINEERING

Within the current global economic scenario, Mechanical Engineering stands out as one of the leading and driving sectors of industrial manufacturing in Italy. In terms of per-capita manufacturing production, our Country ranks 2nd in Europe and 7th on a worldwide scale (Confindustria, Scenari Industriali n.7, November 2016).
In this competitive panorama, and in order to respond to the requests of a challenging sector, the PhD Programme in Mechanical Engineering provides doctoral candidates with a strong scientific training, fostering and refining research and problem-solving abilities with respect to the academic and non-academic *milieu*. Our Programme, organized within the Department of Mechanical Engineering, relies on the development of an interdisciplinary and integrated high-level educational offer, by focusing on a comprehensive scientific proposal, from conception to realization. All Doctoral Candidates follow a minimum path of three-years, which includes specific courses and lectures, held by Faculty members and foreign professors and experts, in-depth research, laboratories and active cooperation with international industries, institutions and research groups. With this background, our Doctorates are able to blend the exactness of scientific knowledge with the ability to deal with management and industrial issues. In this view, their scientific profiles are suitable for prestigious positions at national and international level within universities and research institutions, large industrial and consulting companies, SMEs.

Research areas

The PhD Programme in Mechanical Engineering covers a number of different disciplines, being devoted, in particular, to innovation and experimental activities in 7 major research areas; all doctoral thesis displayed in the following pages belong to one of these areas:
Dynamics and vibration of mechanical systems and vehicles: this research line is organized into five research areas, namely Mechatronics and Robotics, Rotordynamics, Wind Engineering, Road Vehicle Dynamics, Railway Dynamics. It features modelling of linear and non-linear dynamic systems, stability and self-excited vibrations, active control of mechanical systems, condition monitoring and diagnostics.
Measurements and experimental Techniques: the Mechanical and Thermal Measurements (MTM) group has its common background in the development and qualification of new measurements techniques, as well as in the customisation and application of well-known measurement principles in innovative fields. MTM major research focus is oriented towards the design, development and metrological characterisation of measurement systems and procedures, the implementation of innovative techniques in sound/vibrations, structural health monitoring, vision, space and rehabilitation measurements.
Machine and vehicle design: this research area is involved in advanced design methods and fitness for purpose of mechanical components. Advanced design methods refer to the definition of multiaxial low and high cycle fatigue life prediction criteria, and the assessment of structural integrity of cracked elements, the prediction of fatigue life criteria of advanced materials as polymer matrix composite materials (short and long fibres), the definition of approaches to predict the influence of shot peening on fatigue strength of mechanical components. Gears, pressure vessels and helicopter components are dealt with. Optimal design and testing of vehicle systems create a synergism between the theoretical and the experimental researches on ground vehicles.
Manufacturing and production systems: this research field gives relevance to the problem of optimal transformation of raw materials into final products, addressing all issues related with the introduction, usage, and evolution of technologies and production systems during the entire product life-cycle. PhD activities, in particular, are developed within the following research fields: Manufacturing Processes (MPR), Manufacturing Systems and Quality (MSQ).
Materials: this area is focused on the study of production process and characterization of materials, for structural and functional applications. Excellent research products were obtained both on fundamental research topics (e.g. nanostructured materials, foamed alloys, chemical phenomena in liquid melts, microstructural design ecc.) and on applied research (e.g. failure and damage analysis, texture analysis, high temperature behaviour, coatings for advanced applications, etc.). The research projects carried out in recent years addressed specifically the following research topics: Steelmaking and Metallurgical Processes, Advanced Materials and Applied Metallurgy.
Methods and tools for product design: two main research topics are addressed in this field: PLM-Product Lifecycle Management, which includes process modelling, engineering knowledge management, product innovation methods, systematic innovation principles and methods, topology optimization systems, and data/process interoperability, and Virtual Prototyping, which includes virtual prototyping for functional and ergonomics product validation, haptic interfaces and interaction, reverse engineering and physics-based modelling and simulation, emotional engineering.
Smart Materials and Structures: Smart materials and structures are designed to incorporate capabilities of responding to external stimuli in a controlled way, thus allowing better performances of mechanical structures

and devices, as well as the definition of new means to deliver mechanical functions. This area represents a multi-disciplinary research field, calling for scientific competencies on topics related to Materials, Manufacturing, Measurement Systems, Dynamics, Structural Analysis and Product Design.

Laboratories

One of the key elements of our Doctoral Programme is represented by our laboratories; we feature some of the most unique, active and innovative set-ups in Europe: Cable Dynamics, Characterization of Materials, DBA (Dynamic Bench for Railway Axles), Dynamic Testing, Dynamic Vehicle, Gear and Power Transmission, Geometrical Metrology, High-Temperature Behaviour of Materials, La.S.T., Manufacturing System, Material Testing, Mechatronics, MI_crolab Micro Machining, Microstructural Investigations and Failure Analysis, Outdoor Testing, Physico-Chemical Bulk and Surface Analyses, Power Electronics and Electrical Drives, Process Metallurgy, Reverse Engineering, Robotics, SIP (Structural Integrity and Prognostics), SITEC Laser, Test rig for the Evaluation of Contact Strip Performances, VAL (Vibroacoustics Lab), VB (Vision Bricks Lab), Virtual Prototyping, Water Jet, Wind Tunnel.

Internationalization

We foster internationalisation by strongly recommending and supporting candidates' mobility abroad, for short-term study and research periods up to 18 months. We promote, draft and activate European and extra-European Joint Degrees, Double PhD Programmes and Joint Doctoral Thesis (Cotutelle); our Department is actively involved in EU-based and governmental third-level education agreements such as Erasmus Mundus, China Scholarship Council and Brazilian CONFAP. We have ongoing agreements with MIT (Progetto Rocca) Technion Institute of Technology (Double PhD), École Centrale Paris (Cotutelle), Delft University of Technology (Double PhD), TUM (Cotutelle) and University of Illinois at Urbana Champaign (Cotutelle), Laval University (Double PhD).
Our international network includes some of the highest-level and best-known universities all over the world, such as MIT-Massachusetts Institute of Technology (US); University of California at Berkeley (US); Imperial College London (UK); Tsinghua University (CN); University of Illinois at Urbana-Champaign (US); Delft University of Technology (NL); University of Michigan (US); École Polytechnique Fédérale de Lausanne (CH); Technische Universität München (DE); University of Southampton (UK); Technical University of Denmark (DK); Pennsylvania State University (US); Chalmers University of Technology (SE); Technion-Israel Institute of Technology (IL); Virginia Tech (US); Technische Universität Darmstadt (DE); University of Bristol (UK); The University of Sheffield (UK); École Centrale de Paris (FR); Politécnica de Madrid (ES); Université Laval (CA); Universidad EAFIT (CO); AGH (Akademia Górniczo-Hutnicza) University of Science and Technology (PL); Shanghai Jiao Tong University (CN).

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CRACK INITIATION AND GROWTH IN POWER PLANT STEELS

Bassi Federico – Supervisor: Prof. Stefano Beretta

In recent years, power generation industry is facing new issues given by the need to increase productivity as well as improve flexibility of production due to dispatching priority of alternative power sources. Increasing productivity directly results in operating at higher temperatures while improving flexibility affects the load cycles subject by the components. The interaction between the critical creep and fatigue conditions may then results in unexpected onset of cracks or premature failure of cracked bodies. The development of reliable assessment strategies to evaluate the presence and the evolution of cracks is therefore strongly requested by the industry.

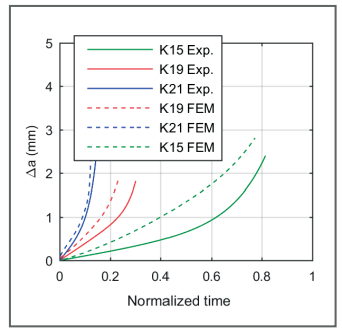
Lately, several international committees have developed codes to assess the acceptability of flaws in metallic structures for high temperature applications. These procedures, despite the large scatter in creep and creep-fatigue resistance properties, divide materials into classes depending on their chemical composition, and tend to consider the lower resistance bound. This choice might result in an over conservative estimation of the residual life of the component.

In this context, the availability of experimental data performed on the same batch material of the plant components, could drastically improve the assessments without affecting reliability. Although in creep crack growth (CCG) conditions, the assessment is successfully performed and validated on components by using the crack tip parameter C* in creep-fatigue regime instead, it is treated by superposing creep and fatigue damages rather than analyse their interactions. From this point of view, the transposition to components of specific crack tip parameters still not considered by these standards, might result in a better quality of the assessments that could, in this way, consider the interactions between creep and fatigue.

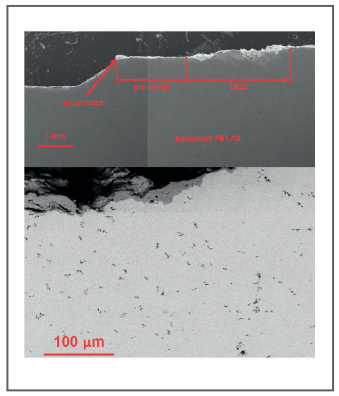
The aim of this research project regards the construction a high temperature (HT) resistance map for a modified P91 power plant steel produced by Tenaris. The uniaxial creep data provided by Tenaris represents a starting point for the CCG, creep-fatigue crack growth (CFCG), and fatigue crack growth (FCG) tests performed at 600 °C, at different stress intensity factors, and at different hold times (CFCG only) in order to complete the HT resistance map. The results of these tests are used to define time-dependent crack tip parameters that govern crack propagation rates which can be used in assessment procedures to evaluate the residual life of components.

A creep testing machine was used to perform the CCG and CFCG tests with a constant monitoring of the load-line displacement and crack size. The target of CCG tests was the identification of the two time-dependent fracture mechanics parameters valid for steady-state creep and small-scale creep conditions respectively: the C* integral and the Ct parameter. Both parameters, if plotted in logarithmic scale with crack propagation rates, exhibit a linear relationship that represents a material property independent from the geometry of the cracked body. The C* parameter was also determined numerically from the load-line displacement records of plane strain and 3D finite element (FE) simulations that combined the creep model by Graham-Walles with a modified cavity growth theory by Cocks and Ashby in order to predict CCG in compact tension C(T) specimens showing a good correlation with the experimental data (**Fig. 1**).

During creep-fatigue tests at reasonable short hold times, the condition of extensive creep may not occur during a cycle. The crack tip parameter in this regime is represented by the (Ct) avg parameter that requires the acquisition of crack propagation and load-line deflection during each cycle. The creep-fatigue average crack growth rates exhibited a power law trend with this parameter that can be transposed to simulate CFCG rates in components.



1. Experimental and numerical CCG rates



2. SEM observation of the crack path

The fracture mechanisms of creep and creep-fatigue have been also studied with detailed micrographs of the crack front section showing that the crack propagation starts with voids concentration at the grain boundaries that coalesce originating creep micro-cavities (**Fig. 2**). Micrographs prove the application of void growth continuum damage approaches to model CCG numerically.

A CCG assessment method was developed to model creep crack initiation (CCI) and growth in pressurised cylinders with circumferential/axial semi-elliptical defects. It is based on the combination of two main criteria, the two criteria diagram (TCD) and C*ref approach recognised and accepted by several assessment procedures. Both approaches strongly depend on uniaxial creep and CCG data obtained from experimental tests. Thanks to this procedure, CCI and growth have been calculated for a P91 pipe subject to internal pressure with an axial defect on the inside surface and compared with alternative assessment codes that resulted to be too conservative.

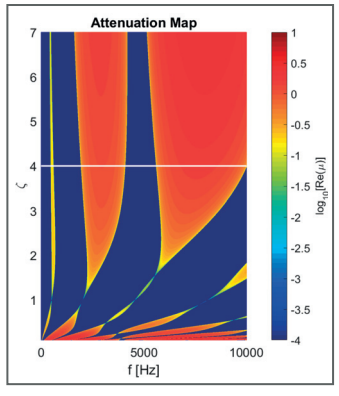
In creep-fatigue conditions instead, the residual life of a component depends on the (Ct) avg parameter that actually accounts for the interaction mechanisms between creep and fatigue damage. This parameter is defined under the hypothesis of partial creep reversal thanks to the creep reversal parameter Cr determined from experimental CFCG tests. The (Ct)avg parameter was integrated in the R5 TDFAD approach to evaluate creep-fatigue crack initiation and propagation. This assessment strongly depends on uniaxial creep data, CCG tests, and FCG tests in terms of Paris-Erdogan law that was collected from dedicated tests. CFCG was calculated for the same pipe geometry previously mentioned according to a combination of the analytical definition of the creep zone size and a numerical estimation C*. As expected, at low hold times (0.1 and 1 h) the fatigue damage tuned out to be dominant reducing the residual life drastically.

Lastly, with the aim to improve the quality of future assessments, the C* parameter of pressurised cylinders was investigated by means of FE analyses with different crack configurations. These simulations extend the aforementioned FE CCG analysis to large scale components and, if integrated with an opportune model of cyclic plasticity, they could represent the creep-fatigue interactions, one still challenging target of computational time-dependent fracture mechanics.

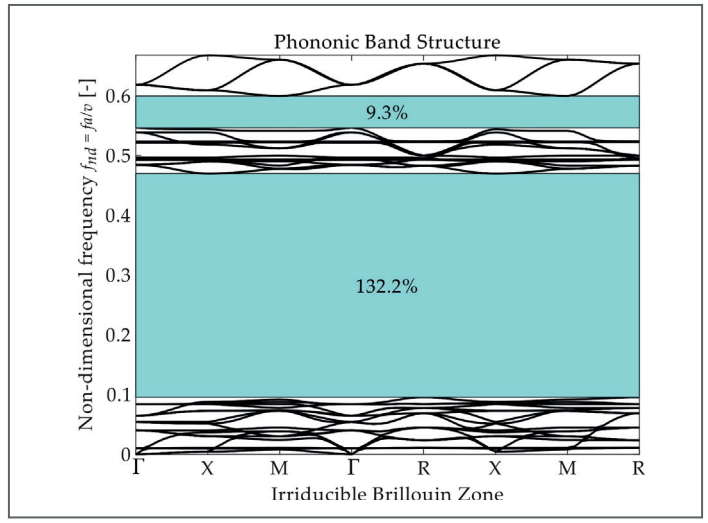
ON THE DESIGN AND CONTROL OF PERIODIC STRUCTURES

Belloni Edoardo – Supervisor: Prof. Francesco Braghin

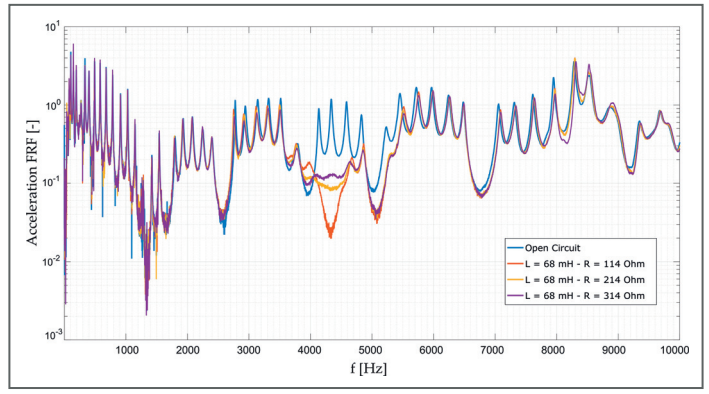
A periodic structure is obtained by the repetition in space of a fundamental block, the so-called unit cell, characterized by internal variations of geometry and/or material. This design allows to obtain a peculiar frequency response function, in which there are wide attenuation zones named bandgaps. This phenomenon, linked to Bragg scattering, has been widely used for electromagnetic waves (i.e. photonic crystals) and more recently for acoustic/elastic waves (i.e. phononic crystals).
A bandgap is created when the wavelength is close to the unit cell length, thus it is both related to unit cell dimensions and wave propagation velocity, i.e. the elastic properties of the material(s).
In general, the higher the local impedance mismatch, the lower the first bandgap frequency.
Thus, for low frequency designs, an unfeasible structure would be required. To overcome this issue, materials endowed with periodically distributed locally resonant elements, belonging to the family of metamaterials, are tailored to peculiar design goals.
This thesis focuses on the design of both passive and semi-active periodic structures. The first step is to find a design method valid both for phononic crystals and locally resonant metamaterials.
For the case of one dimensional periodic structures, a well-known procedure is the use of the transfer matrix, i.e. a matrix that links the left and right side state vectors (composed by displacements/rotations and forces/moments) of a unit cell. A transfer matrix can be derived following different approaches, and in this thesis two procedures are discussed. In particular, an analytical method to always end up with a symplectic transfer matrix is provided. This condition brings to a reduction of the computational burden because the eigenvalues of the matrix are always in reciprocal couples (i.e. a left and a right propagating wave). Then, applying the so-called Floquet-Bloch boundary conditions and the Floquet theorem, it can be shown that these eigenvalues are representative of the wave propagation behaviour along an equivalent infinite periodic structure. Thus, the analysis of a periodic structure can be limited to the study of its fundamental unit cell (and for one-dimensional periodic systems an analytical closed form exists). Furthermore, a method to identify a set of non-dimensional design parameters, which can be plotted in maps so to see their reciprocal influence, is presented. **Figure 1** is an example of a design map for a beam: the bandgaps (coloured areas) are plotted as a function of the ratio of impedance of two consecutive sections inside a unit cell, ζ, and the frequency. The white line refers to a configuration chosen for the experimental validation: measured data are in good agreement with analytical results, which are further corroborated by a Finite Element (FE) simulation and the Spectral Element (SE) method.
The second step was to extend this approach to a 3D phononic crystal endowed with a full bandgap. The dispersion plot of such crystal is shown in **Figure 2:** the first bandgap is the widest obtained in literature until now. Results are confirmed experimentally, and hints to further widen this bandgap are also provided. A prototype of a 3D locally resonant metamaterial has also been manufactured and tested, with a bandgap centred at 180 Hz.
The third step has been to extend the approach further to semi-active periodic structures: a set of piezoelectric patches is periodically glued in couples on the two sides of an Aluminium beam. This arrangement induces bandgaps being a periodic structure. If a RL shunt circuit is connected to each patch with electric resonance tuned at a desired frequency, a wider rejection zone can be obtained. **Figure 3** shows the frequency response function of such semi-active periodic structure at changing resistors: the higher the resistance, the wider the attenuation zone in frequency, but the lower the maximum attenuation. These results are obtained experimentally, after a design phase made with non-dimensional maps and FE/SE simulations. In particular, the use of design maps allows to design the system both from a mechanical and an electrical point of view at the same time, and the mutual influence of parameters is highlighted.
Hints on the use of the generalized coupling coefficient for an optimal tuning of the circuit are provided.
Future developments of this thesis will include a further increase of the full bandgap in frequency, a deeper analysis of locally resonant metamaterials and different designs of the electrical networks.
To conclude, some preliminary ideas on active control are provided.



1. Non-dimensional design map (the white line refers to the configuration chosen for experiments)



2. Dispersion plot of the 3D phononic crystal. The first two bandgaps are highlighted



3. Effect of shunt tuning with different resistors: a wider attenuation zone is obtained linking two adjacent bandgaps

FLUID FILM BEARING MODELLING AND EXPERIMENTAL CHARACTERIZATION

Dang Phuoc Vinh – Supervisor: Prof. Paolo Pennacchi

Hydrodynamic journal bearings are essential power transmission elements which are carrying increasingly high loads because of the growing volume specific power in numerous machines. Industrial rotating machinery for both low and high rotating speed with high loads, such as centrifugal compressors, steam turbines, pumps and motors, employs journal bearings for supporting rotor. The aim of this thesis is to study the static and dynamic behaviours of two kinds of hydrodynamic journal bearings, namely tilting-pad journal bearing and plain journal bearing under various working conditions by numerical simulations as well as experimental tests.

Tilting-pad journal bearings (TPJBs) are widely used in high rotating speed machines operating under low to medium loads mainly because of their high stability compared with plain or fixed-arc journal bearings. Theoretical models using for the dynamic response estimation are especially important for the design stage of modern high speed rotating machinery. Besides, experimental results are vital to fully understand the bearing behavior and to enhance theoretical modelling. At the same time, bearings with non-nominal geometry due to manufacturing error may alter rotor-bearing system dynamic behaviour compared to the systems with nominal geometry ones. Moreover, for operating conditions in which the load direction changes rapidly, studying the effect of the load direction is very important, particularly when analysis of the dynamic performances of the TPJB is needed.

Plain journal bearing, in general, is the simplest and cheapest type of bearing. They are also compact and lightweight, and they have a high load-carrying capacity. In addition, plain bearings are usually used in slowly rotating applications. Critical applications are represented by machines with medium/large diameter shafts, characterized by both low tangential speeds (less than 1 m/s) and high loads (specific pressure higher than 10 MPa). High viscosity oils are usually employed in these cases (ISO VG grade higher than 100) in order to prevent possible failures of the bearing due to contact friction. Thermo-elasto-hydrodynamic (TEHD) model, taking into account the large deformation of the bearing under large loads, is essential to accurately predict the oil film pressure distribution as well as the oil film thickness and is very useful during the design phase.

In the first part of thesis, a theoretical analysis of the influence of the load direction on the static and dynamic characteristics of a rocker-backed five-shoe TPJB is investigated. An analysis is performed for a TPJB using a non-nominal geometry, that is, with a different preload factor for each pad. The numerical simulation using a TEHD model considers both pad and pivot flexibility and a simple thermal model only for the oil film temperature to accurately predict the performance of TPJBs. The model also accounts for pivot stiffness of pads which are determined by a model based on the Hertz contact theory and the experimental measurements. The analytical results of the bearing behaviour are then compared with the experimental measurements for a real bearing having pads with different geometries due to manufacturing errors. The author investigated the performances a five-pad TPJB under three main conditions, namely: (i) the bearing with real dimensions, i.e., different clearances for each pad; (ii) effect of load direction, i.e., the load direction does not follow the more commonly studied LOP and LBP configuration; and (iii) the experimental measurements have been carried out and compared to numerical simulations. A robust estimation method is introduced for the calculation of experimental dynamic coefficients. The procedure for the bearing geometry estimation from the experimental measurement of the clearance profile is also described. The results show that the numerical journal locus of nominal bearing obtained by changing the direction of the static load is a “smoothed pentagon. On the contrary, the journal center loci (the prediction as well as measurement) have irregular shapes. This point should be taken into account in the alignment procedures of rotating machines. Besides, the load direction has a strong effect on the minimum oil-film thickness but has a slight effect on the oil flow rate and the power dissipation. The influence of the load direction has a stronger effect on the dynamic characteristics of the tilting pad bearing than on the static characteristics. The predicted dynamic coefficients for a non-nominal bearing geometry can be significantly different from those of a nominal geometry. Furthermore, the cross terms are no more negligible if compared to a nominal geometry. Also, among the dynamic coefficients, the cross-coupled stiffness coefficients have the best agreement between measurement and prediction. After verification of the numerical model for TPJBs, a TEHD model for plain journal bearings is developed. Characteristics of the two axial grooves journal bearing under severe operation conditions are analyzed and compared with the experiment measurements. Two different lubricants with different viscosity, namely ISO VG150 and ISO VG220 oils are used and compared.

To measure the pressure and the oil film thickness during the shaft rotation, a hollow shaft has been equipped with a pressure probe and a proximity probe. The rotational speed ranged from 60 rpm to 1440 rpm, and the applied load varied from 0 kN to 400 kN in the vertical direction. Results of the dynamic coefficients, static position of the shaft, hydrodynamic pressure, temperature distributions on the bearing, oil-film thickness and bearing deformation under several operating conditions are presented and discussed. Based on our findings, the author observe that the dynamic direct stiffness coefficients strongly depend on the applied static load, rotational speed and excitation, especially the direct stiffness coefficients in the loaded direction, K_{yy}. The direct stiffness coefficients increase with the increase of the static load. An opposite trend is found for the direct damping coefficients, i.e., they decrease with increasing of the applied static load or shaft speed. Effect of viscosity on the dynamic coefficients is very small and negligible. The pressure at the loaded part of the bearing increases with the increase of the applied static load. The maximum measured pressure values increase about 6 times in the considered range of the static load, i.e., from 9.5 bar at 0 kN to 55.6 bar at 49.1 kN. The maximum pressure position for all tests occur approximately 105°. A decrease in the pressure occurs from 150° to 180° in the cavitation zone. By increasing the rotational speed, the oil-film thickness tends to decreases due to the thermal expansion of the shaft. In addition, the oil-film thickness profiles are not similar to circles. This observation is probably because of the shaft vibration and flexibility of the system. The bearing deformation can be calculated based on the oil-film thickness. This deformation increases with the increase of the static load and mainly occurs in the loaded part of the bearing. The increase in the static load or rotational speed caused the temperature increase in the loaded part of the bearing. At the bearing angle of 112.5°, close to the minimum film thickness position, the maximum temperature occurs. Finally, the oil outlet temperature seems to be independent with the applied static load, but it significantly depends on the rotational speed in both cases using the ISO VG150 and ISO VG220 oil.

The obtained results can be used in the development and validation of mathematical methods for research into hydrodynamic journal bearings.

STUDY, QUALIFICATION AND APPLICATION OF AUTOREGRESSIVE TECHNIQUES FOR STRUCTURAL HEALTH MONITORING

Datteo Alessio – Supervisor: Prof. Alfredo Cigada

Co-supervisor: Prof. Giorgio Busca

Structural Health Monitoring (SHM) is related to a wide range of topics regarding civil, mechanical and aerospace systems. Briefly, it concerns the development of an automated monitoring system that provides useful and quantitative information on the "health" of a structure. This means to detect any incipient damage or any growth of inherent faults. In order to get the maximum advantage from this tool, the detection should be ideally instantaneous. Over the last few years, the interest on SHM in civil engineering has become more and more significant with the increasing performances of the hardware available to process the acquired data. Basically the interest is driven by economic and safety advantages. For instance, after an extraordinary event, like an earthquake in civil contexts, theoretically it should be possible to understand if a structure could work properly and safely by means of a SHM system, or if it needs an intervention to re-establish the working condition. Moreover, it could be possible to prevent a catastrophe, like a collapse of the structure. The collapse is a sporadic event but when it happens it could have serious consequences.
A focus of this thesis is to perform a qualification of the Autoregressive (AR) models in the field of the unsupervised learning and where only the output of a system is provided by a single sensor is available. This is the worst scenario in terms of the amount of information available on the system taken into consideration and this is chosen to conduct an analysis of these techniques, investigating their limits of application.
The choice of the pure autoregressive (AR) model in the context of unsupervised learning performing a statistical pattern recognition is functional to the feasibility study to realise an online real time SHM system for a real structure. The AR model and the statistical pattern recognition request a relative low computational cost to achieve this declared trait. Moreover, to reach this goal it is necessary to understand which is the minimum recognisable damage and which role the interaction of a system with the real word plays. This study qualifies the use of the AR model suitable for SHM considering two main aspects which influence the performances of the damage detection: the intrinsic uncertainty of the AR models and the operational/environmental variations in the system. Both of them are always present in a real case application and they are never negligible.
The tool used to quantify the role of uncertainty on damage detection with the autoregressive models is the Uncertainty Propagation (UP). In this way, the robustness of the damage feature is established. Moreover, the Global Sensitivity Analysis (GSA) is used in order to quantify the variation of each AR parameter due to a variation of the represented system, understanding which mechanical parameters more influence the AR parameters. Since all the AR parameters, or any their function, in the SHM can be used as a damage feature. The qualification of the AR parameters in this context is a lack of the literature. The results of the GSA and the UP analyses show that not all the AR parameters carry the same type and the same amount of information. This is an important result because commonly the AR parameters as damage feature are used all together and with the same importance. These result, also, justify the use of the Principal Component Analysis (PCA) on the AR parameters describing different scenarios of the system in order to enhance the damage identification. Moreover, the effects of environmental and operational

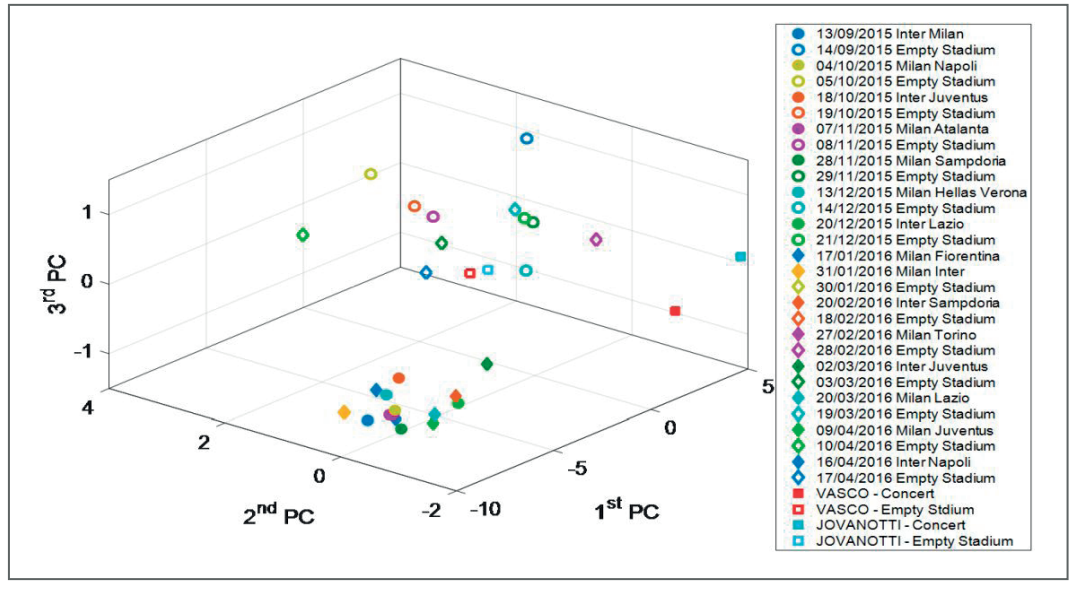
1. Present outside view of the Meazza stadium

variations are considered, which are the most evident obstacle to the application of SHM on a real system when only the output is available and in the unsupervised learning context.
Thus, this work aims at analysing the use of known techniques, such as PCA and cointegration in combination of the AR models. The experimental validation considers a single sensor and actual temperature variations, which is very rare in the literature. Temperature variations are one of the most important effect that generates false positive from the damage detection strategy. The aim is to understand if it is possible to achieve a better separation between the effects of damage from the ones due to the environment on which a real system operates, knowing the output and the normal conditions state.

The scores of the linear principal components show a good representation of the system with operational variations and changes in temperature. To identify the cases of temperature variations and abnormal condition at the same time is necessary to consider the principal curves.
Finally, the use of autoregressive models in combination with PCA is applied to a real operative structure, the Meazza stadium based in Milan.

This strategy can correctly describe the state of a grandstands of the Meazza stadium using few indexes.

The scores of the principal components show a long term and a daily trend, then it is possible to implement a machine learning strategy to take into consideration these dependencies and perform an automatic damage detection.



2. Centres of mass of the principal components related to different state of the grandstand.

PRE-REDUCED IRON USE IN STEELMAKING FURNACES

Di Cecca Cosmo – Supervisor: Prof. Carlo Mapelli

Steel production is one of the most important and fundamental industrial processes. In the context of modern steelmaking, environmental impact plays an increasingly important role. The growing demand for sustainability in ironmaking and steelmaking processes is leading industries into a transition towards green metallurgy. This encourages researchers to improve the steelmaking process according the different production avenues. The main steel production routes are the iron ore and the scrap ones. The environmental footprint of the first kind of production differs in comparison to the latter; this is due to the different plant sizes and production methods involved.

Blast furnace (BF) plants are created for the production of huge amounts of steel. A blast furnace is a continuously operating counter-current shaft furnace where coke and burden are charged in alternating layers. In the integrated mills all raw materials must be prepared with several processes suitable for the production of liquid iron. Cokemaking in particular has a large environmental impact in this regard.

The molten pig iron produced is converted into steel inside the Basic Oxygen Furnace (BOF).

Scrap is the traditional input for Electric Arc Furnace (EAF), but the recent market condition characterised by shortages of high-quality, low-price scrap has prompted steel producers to pursue charge substitutes. Worldwide, scrap makes up the greatest amount of the metallic charge for EAFs, while the remainder consist of Direct Reduced Iron/Hot Briquetted Iron (DRI/HBI), pig iron and hot metal. Modern direct reduction technologies were developed for production of a new kind of raw material. Currently, while gas-based technologies have a lower impact compared to coke-based techniques, the DR process is also used for reducing overall CO_2 production. DRI and HBI adoption in EAF has become a key part of modern steelmaking practice, in particular when nitrogen and unwanted metals need to be controlled.

Modern society continues to put pressure on steelmaking research to reduce emissions and grow the share of recycled material. The geographical locations of modern steelmaking plants, especially in Italy, are near cities, and blast furnaces and electric arc furnaces must be developed in order to reduce overall emissions. The combination of high costs for new plant installations and the need to lower environmental impact mean that conventional cokemaking and sintering processes are two production steps that must either be developed or eliminated.

This work aims to restrict production of this pollutant material by limiting the use of molten pig iron in the basic oxygen furnace. Such material is replaced by means of pre-reduced iron (HBI), while keeping the characteristics of the process unchanged and avoiding the development of emission phenomena. This is achieved through dedicated experimental campaigns and the creation of ad hoc operating practices.

The performance study can be achieved using several techniques based on complex algorithms or tools such as simulation programs. Among these the definition of different KPIs (Key Performance Indicators) that help in the management and evaluation of productive and environmental aspects of a steel mill must be performed. Yield of raw materials used in the process is the most important KPI in this study.

An experimental campaign was carried out in order to assess the possible increase of the cold charge loaded into the BOF through HBI as a substitute for cast iron. This target was pursued through experimental campaigns regarding the replacement of the hot cast iron with HBI (in the case of the BF route), and the increase in metallurgical yield that allows for a reduction in the overall costs of the heats in the EAF route.

In the first step, the effect of the raw materials on the overall metallurgical yield was studied. The tendency towards slag overflow was also evaluated as a function of the new cold charge mix, the fraction of the different types of charged scrap and their compositions.

The starting point entailed the definition of a new operational practice focused on the removal of silicon, an element that promotes the slopping phenomenon and thus worsens process performance.

Moreover, the data recorded will allow the correct quantification of the energies in the different steps of the process and the indirect definition of the steel's chemical evolution through oxygen activities and an Ellingham diagram

The EAF cycle exerts a lower environmental impact, in contrast to that of BOF. This consideration has foreseen a study where the pre-reduced material was used to increase the yield and decrease the cost of the heats.

Different automation levels available in the steel shop make it possible to use two different approaches: the first approach is based on a quantitative analysis when time-dependent datasets are not available, while the second approach is based on a deterministic model when datasets are compatible with advanced simulation tools.

New technological innovations have led EAF steelmaking towards software support in the management process. This system can run in off-line or on-line mode according to the availability of information technology services.

The adoption of modelling has led to better insight into the melting process and consequently into an increment in overall operation of the EAF.

All modelling activities depend on data availability, and although the EAF process model is well designed, it needs further integration, modification and development in a software framework. The model presented in this work takes into consideration certain fundamental aspects, such as the fact that the melting of steel is a dynamic, non-linear and time-variant process. The process involved in this simulation takes into account electrical, chemical, thermal and mass transfer equations

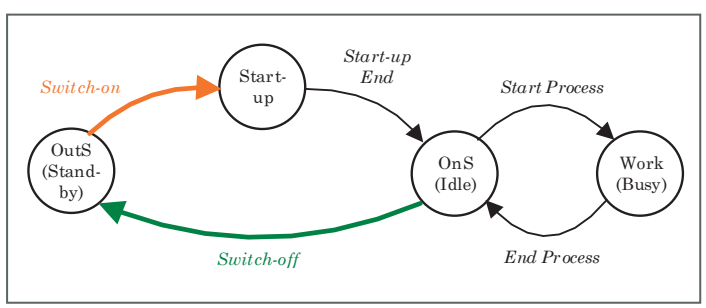
The results will be integrated into the normal operating procedures and the benefits of the new practices will be evaluated. HBI will substitute for pig iron without affecting the metallurgical yield. The progress of oxidation during the oxygen blowing process involves the same thermodynamic conditions identified on the oxygen potential diagram (Ellingham diagram). This makes the process repeatable in its execution despite the different HBI quantities loaded avoiding the occurrence of the slag overflow phenomenon. The evaluation performed on equivalent CO_2 per tonne of pig iron produced by the blast furnace will confirm the results obtained.

In EAF the charge of HBI will show a high contribution to improve the metallurgical yield when compared to the most frequently used kind of scrap. Finally, the economic aspect will be also considered and the use of HBI (instead of new thin steel scrap) does not affect the metallurgical yield of the charged material.

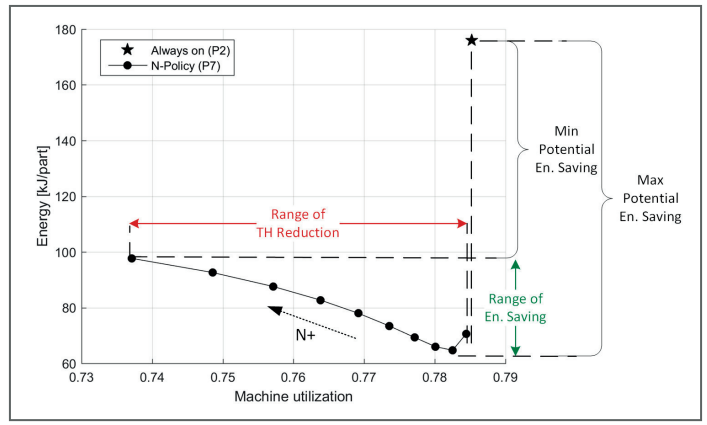
OPTIMAL STOCHASTIC SWITCHING OF MACHINE TOOLS IN ENERGY EFFICIENT MANUFACTURING SYSTEMS

Frigerio Nicla – Supervisor: Prof. Andrea Matta

Manufacturing industries have always focused on productivity improvement and quality achievement, but, in the last years, the environmental impact becomes critical as well. Nowadays, both practitioners and researchers are dealing with energy assessment, and they are analyzing measures to improve energy efficiency of manufacturing systems.
In the particular case of machines executing machining operation—i.e., machine tools in this work—the control of machine states is one of the most promising measures at machine level. This state control aims to reduce the energy demanded when the machines are idle by start/stop features such that the machine is switched off/on according to certain rules. Critical barriers for a practical implementation are usually related to system productivity, therefore, any new solutions have to keep high the production performance and, at the same time, improve system sustainability.
This work aims to improve the sustainability of manufacturing systems by changing the way in which the state of machines is controlled. First of all, the control has to take into account that machine tools may need a transitory—i.e., startup— before resuming the service (**Fig. 1**). As a consequence, a delay in production may eventually be a side-effect of the control policy affecting machine productivity. The second issue is related to the amount of information available at machine level, often limited in practice. In some cases, data are not available at machine level because a communication interface with the monitoring system or the system supervisor does not exist. In addition, system uncertainty in part arrival, part processing, and machine startup duration makes the system and the control stochastic. Therefore, a framework for the energy control of machine tools in stochastic manufacturing systems is developed together with control models where machines require a startup procedure to resume the service.
Several control policies are described according to the amount of information to which the control have access. In particular, two types of information are used: (1) time information from the load/unload operations—i.e., the time instants when a part is loaded to be processed or a part leaves after process completion— and (2) buffer occupancy information. A general control policy based on time information is designed under the assumption of stochastic arrivals and no input buffer. Particular effort is devoted to find structural properties of the optimal control. A dynamic programming based model, where the machine state is controlled using upstream buffer information, is developed. Under certain conditions, the optimal policy is proved to be exhaustive and threshold based. A mapping of the optimal control among the most significant factors for queueing systems with finite buffer capacity is provided. The minimization of the expected energy consumed for the production of a part is pursued while constraints on machine productivity and system performance are considered. In addition, the policies and their optimal conditions are studied on the basis of a set of numerical cases. Some numerical cases refer to a real CNC (Computer Numerical Controlled) machining center that we experimentally characterized to estimate its power demand. **Fig. 2** represents an example of application of a buffer based control policy.
A production line with finite buffer capacities when policies are applied at machine level is studied. Discrete event simulation is used for performance evaluation, with an ad–hoc template built in Arena© for modeling a general machine controlled with an energy state control policy. The value of the information is discussed in terms of system performance under a certain policy. In addition, we have provided main guidelines to apply the control in practice together with some benchmarks for achievable energy saving. Besides the scientific results, this work represents a contribution towards the answer to a relevant industrial issue, which is the practical implementation of machine control during idle times.



1. Machine state model with a transitory to resume the service

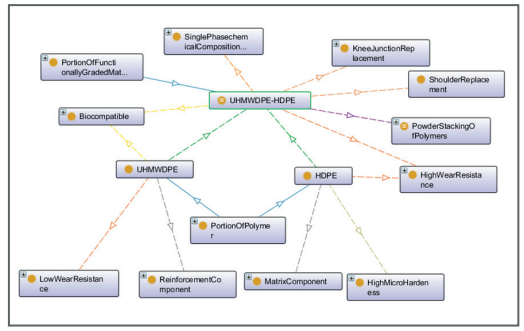


2. Expected performance of a machine controlled with buffer information

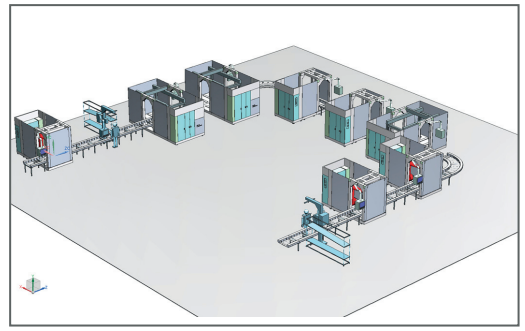
KNOWLEDGE BASED ENGINEERING AND ONTOLOGY: ROLES IN DESIGN AUTOMATION AND PRODUCT CONFIGURATION

Furini Francesco – Supervisor: Prof. Giorgio Colombo

Actual trends in product development process consist in the increasing digitalization of data and virtualization of processes. Digitalization of data involves an improvement in terms of accessibility, maintainability and sharing of the information and is a fundamental requirement for the interoperability; in the other hand the virtualization of processes involves a better integration of the different activities, reduction of development time, evaluation of alternatives, and implementation of best practices. Digital data and virtual processes are combined in order to automate the product development and configuration process, improving the final quality of the results. In this scenario, maintenance of applications and knowledge bases is difficult, because of the low flexibility of IT tools and their platform dependency, rigidness of systems and data structures. In these terms there is an high risk of loss of knowledge, data and information due to the obsolescence of computer systems.
A solution to avoid the previous reported problems consists in the adoption of a good knowledge management strategy, permitting a reliable representation and formalization, that is also implementable with conventional programming and database techniques. In Knowledge Based Engineering (KBE) field, Object Oriented approach (O-O) is the most used technique to represent and implement knowledge models aimed at design automation.
Another technique for knowledge management, Ontology Engineering (OE), is a growing approach aimed at knowledge management and representation considered in fields like military/ defense and bioengineering.
The goal of the thesis is to evaluate the roles of OE and O-O in the field KBE for product design and configuration. The research will be applied to the academic and industrial study cases, in which the focus is to assist the engineers with reliable methods and tools for knowledge management to support automatic design activities.
The methodological approach consisted in different steps.
The first one concerned the examination of the main contributes in technical and scientific literature about Ontology Engineering and Object Oriented Approach, analyzing the typical domains of application and extracting the main characteristics.
The second step consisted in the verification of the feasibility of OE, OO and their combination by means of academic and industrial study cases. The third step consisted in the detailed comparison of the results of the application of these techniques and discussion about the capabilities and contributions in the KBE domain.
The first case study regarded the management of the Functionally Graded Materials knowledge: due to several investigations in this field, there lack of standardization about data related to experimental activities and processes. For that, the repositories are located in different, distributed and heterogeneous data sources, presenting several structures and involving problems related to data exchange and interoperability in the scientific community.
The solution for this problem consisted in the definition of a standard schematization of the data structures about FGM with the help of OE, with the description of materials, components, manufacturing processes, applications, best practices and material properties in order to retrieve data in local and distributed environments.
For that activity, the open source software Protégé has been used operating with OWL2 DL language.
An example of characterization of an FGM material is illustrated in illustrated in **Fig. 1**
The second case study regarded the problem of long lead time in the configuration of production systems in distributed environments. In particular, an assembly line for cylinder head valve has been analyzed focusing on the elaboration of technical offers characterized by CAD models, BOM and technical docs.
The solution to decrease the lead time consisted in the definition of a standard and shared structure of data and information, with the automation of the process for the generation of the layout. For that, in first instance, the knowledge about design of assembly lines has been mapped with the help of OE. After the identification of configurable modules, a configurable architecture has been formalized and integrated in an automatic design system. The tools considered for this activity are open source software Protégé (operating with OWL 2 DL language), SQL server, VB.NET and Siemens Rulestream. In **Fig. 2** is illustrated an example of layout design.
The results of the application of OO and OE approaches are resumed in the **Table 1**.
The summary of the results of the application of such methodologies demonstrated that OE approach is useful for the description and analysis of the domain of study in order to get data structures and relations. Its application to academic fields is fundamental for exchange of data and interoperability inside the scientific community, while a definition of a general data structure is useful to organize data and information in distributed industrial environments.
OE approach supports development and maintenance of knowledge with independent platform implementation codes, makes knowledge management independent with respect to development and maintenance of software applications of configuration, elaborated with the help of OO approach.



1. Mapping of information about UHMWDPE-HDPE material



2. Example of configuration layout

TABLE 1 RESULTS OF THE APPLICATION OF OO AND OE APPROACHES

	Object Oriented approach	Ontology Engineering approach
Representation of Data Structures	Good	Good
Representation of knowledge semantics	Poor	Good
Representation of knowledge rules	Good	Neutral
Representation of modular architectures	Good	Neutral
Implementation with mark-up languages	Poor	Good
Platform-Independence	Neutral	Good
Data Integration and Interoperability	Poor	Good
Implementation with OO programming languages	Good	Poor
Integration in Software Design systems	Good	Neutral
Integration with DB languages	Neutral	Good

METROLOGICAL ANALYSIS OF TIME-OF-FLIGHT CAMERAS PERFORMANCES FOR MULTIPURPOSE 3D RECONSTRUCTION

Giancola Silvio – Supervisor: Prof. Remo Sala

Co-supervisor: Prof. Alfredo Cigada

Time-of-Flight camera are novel 3D vision sensors that are becoming more and more common. Multiple applications such as *field reports, cultural heritage documentation, robot navigation, medical disciplines* and *entertainment* make use of such technology for people tracking and digital reconstruction purposes. Such device makes use of the Time-of-Flight principle to provide depth maps that represent the geometrically reliable reconstruction of a surrounding scene.

In order to qualify the performances of such devices, the uncertainty in depth measurement for the commercially available Microsoft Kinect V2 state-of-the-art Time-of-Flight camera is estimated following the Guide to the Expression of Uncertainty in Measurement (GUM). Time-of-Flight LiDAR signals are investigated, questioning the reliability of the 3 main signal frequencies.

A pixel-wise uncertainty investigation focuses on the normal distribution of the depth uncertainty in space. Depth measurement is sensitive to temperature and an extensive usage induces significant drift in depth measurement reaching up to 6 mm that can be minimized, using an external cooling system. The random component of the uncertainty increases linearly with the sensor distance, bounded by 1.5 mm up to 2 m range and reaching 3.5 mm at a 4.5 m range. The random uncertainty has a cone shape, due to the illumination system that enlighten the scene with its LiDAR signal. In the corner of the matrix sensor, where only a small amount of light project, the random component error reaches up to 15 mm. Successive studies showed a *wiggling* rror for the biased component of the uncertainty in depth, bounded in ±15 mm. This bias is accentuated on the corner and can reach up to tens of millimeters.

Extended test shows up the capacity of the Kinect V2 to measure simple shapes in the surrounding environment. The most important component of the systematic uncertainty comes from the mixed pixels effect and the multiple path reflection, that yields on biases reaching up to 80 mm. Such bias is the main source of uncertainty in Time-of-Flight camera; scenes to reconstruct have to be chosen with caution, since any concave geometry can create multiple path reflection.

Accuracy and precision in depth is evaluated for the Kinect V2 device under multiple circumstances and successively compared with a structured-light depth camera. Unlike Time-of-Flight technology, structured-light systems provide good accuracy but worst precision. Nevertheless, multiple measurements improve the random component uncertainty of the structured-light system, but can't correct the bias component of the Time-of-Flight depth measurement.

Finally, the people tracking capability of the Kinect V2 is compared with a Multi-View Stereoscopy system in a rehabilitation project where skeleton tracking performance are assessed. The Kinect V2 shows an improved accuracy respect to single market placement tracking, a reduced precision of around 1 mm for the wrist joint and an improved experimental setup that does not require marker placement.

Successively, the reconstruction problem is investigated, in particular how additional information that can be used to improve point cloud registration.

In a first attempt, geometrical features are used for the keypoint correspondences estimation. Then, inertial information is merged to improve registration robustness over orientation.

Focusing on registration, the core of scene reconstruction, the Iterative Closest Point (ICP) algorithm convergence is investigated.

Using full-size point clouds from the Kinect V2 results in not being timely efficient. Downsampling is necessary and three-dimensional (3D) keypoints detection algorithm are investigated. They show to be less repeatable and less time-efficient than two-dimensional (2D) keypoint detectors, but still provide information in case of scarce-light condition and improve point cloud alignment robustness.

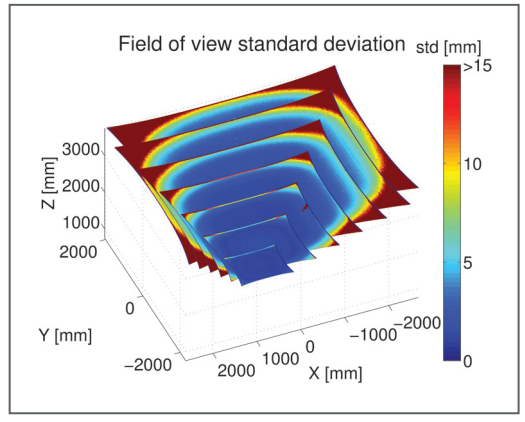
Regarding description, 3D features provide extended information for a given keypoint. Kinect V2 being a projective 3D camera, 2D keypoints are usually found and described efficiently in RGB frames and successively reprojected into 3D space.

These 3D keypoints are used in Simultaneous Localization and Mapping (SLAM) pipelines for 2 applications: an archaeological find modelling and a crime scene reconstruction. They are compared to state-of-the-art 2D SLAM techniques, as well as structured-light, laser scanner and laser triangulation reconstruction solutions. For medium scale reconstruction, SLAM techniques are preferred and 3D keypoints features are more reliable respect to 2D descriptions. In general, SLAM techniques provide reconstruction with a 10 mm mean error.

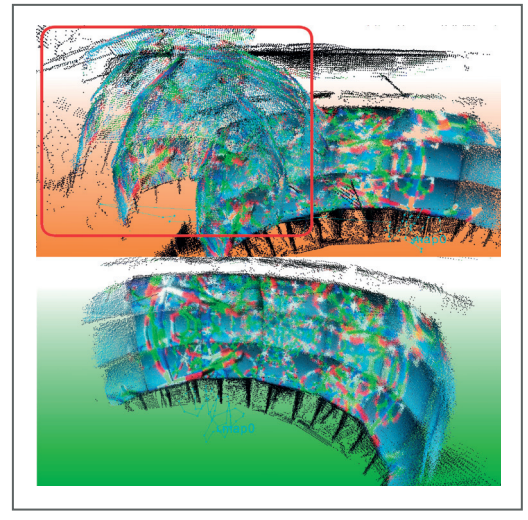
In a successive step, Inertial Measurement Units (IMU) information are used in registration pipelines. Such devices provide robust absolute orientation measurements. The BNO055 IMU performance is assessed; its orientation measurement is characterized and by a ±2° bias component around the horizontal axes, that reach up to ±15° around the vertical axis, due to magnetic interferences.

Using the IMU absolute orientation measurement as a prior, the ICP algorithm converges in a more global solution. Using it as a hard constraint, both ICP and RANdom Sample Consensus (RANSAC) registration techniques are simplified and linearized in a 3-DoF problem. Kinect Fusion being based on ICP, reconstruction is more robust, alignment occurs in less iterations, elaboration time is improved and real-time reconstruction is possible on a laptop. RANSAC using matched keypoints, an ulterior filter based on distances improve convergence speed to up to 30%. SLAM being based on RANSAC registration method, reconstruction is more robust, especially using the hard constraint, that does not drift in orientation.

In this thesis, the Kinect V2 is characterized for reconstruction purposes, but extension of this work could apply on object detection and tracking. Such field also exploits registration pipelines to find objects on scenes. 3D keypoints can be used, but most interesting application would be to embedded IMU on objects to track, in order to give a prior to the recognition techniques. The same kind of results are expected.



1. Depth precision over the field of view



2. The robustness improvement in registration using an IMU is visible in the SLAM reconstruction. Top: Original SLAM reconstruction. Bottom: Viusal Inertial SLAM reconstruction

ACTIVE ROLL CONTROL OF HEAVY VEHICLES USING EXISTING AIR SUSPENSIONS

Izadi Alireza – Supervisor: Prof. Edoardo Sabbioni

Co-Supervisor: Prof. Federico Cheli

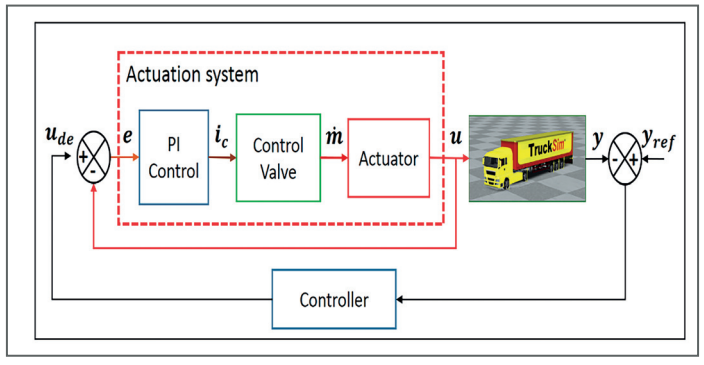
Heavy vehicles are a considerable part of traffic with an enormous contribution in transportation system. Heavy vehicles involve approximately in 35 percent of fatal accidents while 38 percent of these fatalities are caused by rollover which is the most horrible accident. This serious accident occurs due to lack of lateral stability and its consequent damage and cost to roads and occupants is drastically high. This harmful crash influences even passenger car occupants and pedestrians. Considering diverse types of heavy vehicle combinations, tractor semitrailer type causes more than 14 percent of rollover fatalities.

The statistics indicates merely 3 percent of the rollovers are surely preventable by driver while the majority are not avoidable even by using a sophisticated warning system and a highly skilled driver. Therefore, an intervention of advanced active safety systems requires to assist the driver. Moreover, there is a strong negative correlation between steady-state roll stability and the average of rollover accidents: an increase in static rollover threshold of 0.1 g in the range of 0.4-0.7 g causes a 50 percent reduction in the frequency of rollover accidents for tractor semitrailer combinations.

Among different controllers proposed by the state of the art, active roll control is the most promising solution for rollover prevention. The objective of this controller is to tilt the vehicle in contradiction to the passive vehicle and toward the center of the turn to enhance the lateral stability. The required actuation force is generated by a compatible set of actuators which is imbedded in a reliable control strategy. The state of the art presents active anti-roll bars (ARBs) as a capable actuation system with wide bandwidth of around 4 Hz for the rollover controller while there are serious difficulties to implement and commercialize them. Active ARBs have been implemented with different control logics those are studied during this project as well.

This study investigates on designing an innovative active roll control system implementing the full potential of existing air suspension of current heavy vehicles with a minimum possible modification and costs. The objective of the controller is maximizing the lateral stability by reducing the lateral load transfer on axles and improving the rollover threshold.

Different actuation systems and controllers are implemented for rollover controller including three controllers and two actuating systems. To find the best configuration of actuators, the specifications and compatibility of active air springs are technically discussed in collaboration with three nominated control strategies and in comparison to active anti-roll bars from the state of the art.



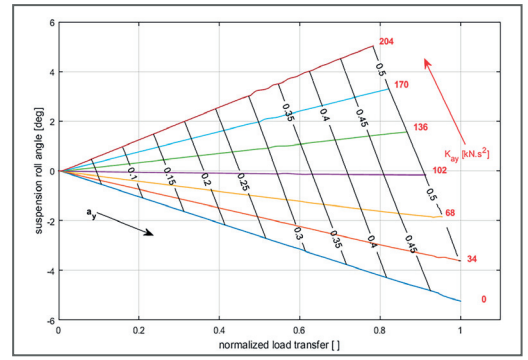
1. The control architecture of the designed rollover controller

The air suspension configuration, the required modification and its performance is scrutinized for the tractor semitrailer of Volvo.

The designated control strategies are a simple proportional lateral acceleration feedback, a full-state feedback and a minimum order feedback control strategy which were selected based on number of measurements (sensors), estimation, and measurement cost, robustness, precise and fast response. Comparisons of the controllers were done in transient and steady state maneuvers. In order to implement the control logics, two linear vehicle models were developed with different level of complicity: a simplified 5 degree of freedoms roll-plane and a 9 degree of freedoms roll-yaw vehicle model. A nonlinear multi-body vehicle model was also developed to verify the implemented control strategies in different maneuvers.

Comparing the active ARBs and the innovative active air springs proves that although the active ARBs have higher capability, the active air springs are compatible and appropriate to be applied in heavy vehicles with air suspension:

- Active air springs are able to improve the rollover threshold by 16% and 35% in steady state and transient maneuvers, respectively and with a very small changes in suspension configuration.
- The peak power consumption is around one third of the active ARBs due to the installation distance.
- Installation and operational cost is very low and their bandwidth is wide enough to cover the roll bandwidth of vehicle.



2. The proportional gain scheduling for the simplest control logic.

Among the control strategies, proportional lateral acceleration feedback control is elite with minimum number of measurements, very low measurement cost, adequately fast response and robust performance to payload position and velocity and as beneficial as the optimal controls. Its proportional gain scheduling was done based on the lateral acceleration and in a pre-processing phase and for all axles of the tractor semitrailer considering the optimal load distribution on axles. These patterns map the corresponding load transfer, roll angle and lateral acceleration to each selected gain for further applications.

Accordingly, active air springs with the proportional lateral acceleration feedback control strategy is the most feasible choice for rollover controller of heavy vehicles equipped with air suspension considering its fast response, enough wider than vehicle roll bandwidth. This rollover controller has considerably low costs and low power consumption for heavy vehicles with pneumatic suspension systems.

TABLE 1: COMPARISON OF ROLLOVER CONTROLLERS WITH DIFFERENT ACTUATION SYSTEMS AND LATERAL ACCELERATION FEEDBACK CONTROL LOGIC

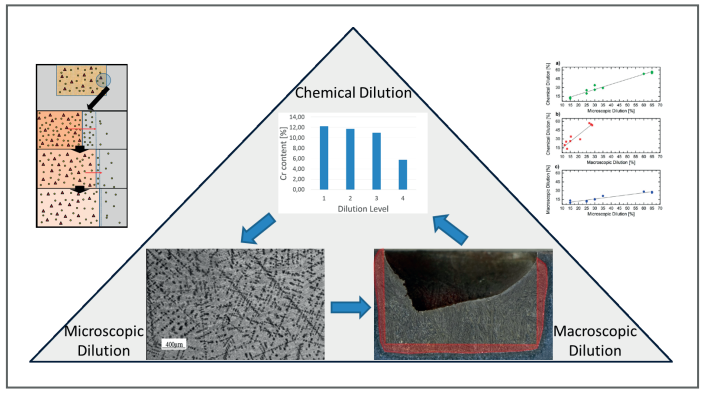
		Air springs	ARBs
Main Features	Steady state improvement (%)	15-16	25-26
	Transient improvement (%)	35-36	35-36
	Robustness to payload position, irregularities and velocity	Robust	Robust
	Power of comparable systems [kW]	3,112	5,925
	Installation and Operational Costs	Very low	Very high
	Bandwidth [Hz]	2,32	4,11

DEVELOPMENT OF IRON-BASED ALLOYS FOR INNOVATIVE POWDER METALLURGY PROCESSES

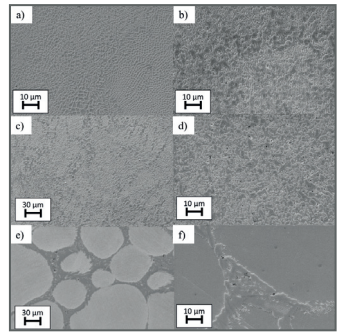
Lemke Jannis – Supervisor: Prof. Maurizio Vedani

Iron-based alloys are employed in several industrial sectors and still steel is the world's most used structural metallic alloy. Nowadays, research focuses on the production of Iron-based alloys by innovative processes like powder metallurgy (PM) techniques. For such techniques the range of available material is yet very limited as the powder nature of feedstock poses processing challenges to scientists and engineers. New alloys have to be developed to fulfil the process inherent requirements. This research work contributes in particular to the development and characterization of steels for powder metallurgy applications, which require high strength and wear resistance.

Spin casting and Selective Laser melting (SLM) represent two important classes of such powder metallurgy processes. The former is a deposition process of thick coatings and is affected by backing steel dilution. Dilution leads to a reduction alloying elements in the coating and has to be considered during the design of powder composition as alloy properties will differ after deposition significantly from those of the base alloy. SLM is an additive manufacturing (AM) process for the freeform production of metal parts. Especially the high cooling rates poses a challenge, but also a promising feature, which could be exploited in future structural and functional parts, e.g. to create fine, anisotropic microstructures. A main objective is to show how the nature of these powder metallurgy processes affects solidification behaviour and mechanical properties, leaving characteristic footprints in microstructural features, defect distribution and anisotropy. Regarding Fe-based hardfacing alloys for spin casting, the effect of dilution on microstructure and wear properties was studied profoundly, precipitating carbides and borides in hypereutectic alloys were determined. By the addition of iron powder to the feedstock material it was possible to simulate backing steel dilution and to determine characteristic threshold intervals at which the hypereutectic solidification mode turns hypoeutectic. Detrimental effects of dilution on hardness, wear performance and solidification range were characterised. The effect of vanadium and graphite additions to hardfacing alloys was also studied. A significant improvement in hardness could be achieved by V additions up to 3% due to the appearance of additional V-rich carbides. The solidification gap remained close to that of the reference alloy, which could qualify these alloys as particular suitable for spin casting. Finally, a model was developed and validated by crucible castings in order to correlate macroscopic, microscopic and chemical dilution effects through an interface by linear regression (**Figure 1**).



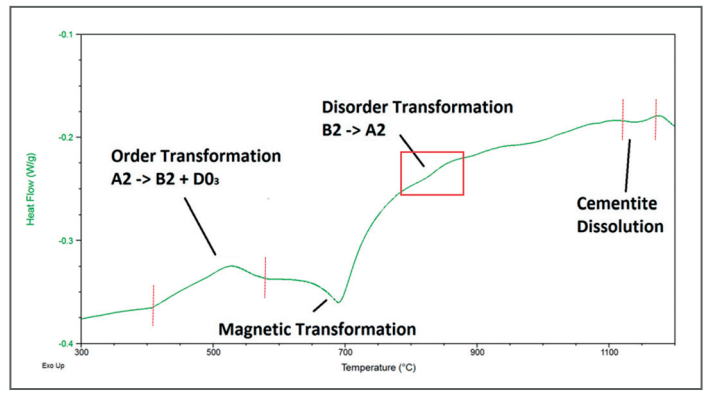
1. Investigation of dilution in hardfacing alloys through an interface. Experiment set-up is shown in the upper left corner: Hardfacing alloy elements diffuse through crucible interface and lower its melting point. Three measurable effects of dilution are presented in the centre sketch: Change in microstructure, melting profile and chemical dilution. The graphs in the upper right corner illustrate the found linear correlations between these effects.



2. High-strength austenitic steel powder blends were prepared by 304CS powder alloying of 316L, built by SLM and heat treated to modify microstructure. Selected micrographs of modified 316L alloys for SLM: a) 316L as built, b) 316L + 5% 304CS, 1100°C annealed for 1 h and water quenched, c) and d) 316L + 20% 304CS, 1150°C annealed for 1 h and water quenched, e) and f) 316L + 20% 304CS, 1200°C annealed for 1 h and water quenched.

The impact of laser parameters, built strategies and alloying on microstructure, defects and tensile properties of SLMed 316L alloy were investigated and discussed. Its microstructure is characterised by overlapping melt pools containing austenitic cells with submicrometric size and regions that grew ruled by epitaxial mechanisms across different tracks. A horizontal build orientation proved to be advantageous over a vertical one for the tensile performance of the material. Then, it was demonstrated how by alloying a 316L grade with a strongly carbide-former 304CS alloy, more wear resistant, high-strength austenitic stainless steel parts could be produced. 316L alloy with 304CS alloy additions could be processed to crack-free condition up to 20 wt. %-addition. At this composition the C content was about 0.42 % and the hardness increased about 82.7%. Heat treatments were developed to modify the microstructure from austenitic grains surrounded by a carbide network into a spheroidised structure. This effect was achieved at best after heating for 1h at 1150°C and water quenching. Selected microstructures of 316L – 304CS alloys are shown in **Figure 2**. Wear resistance of alloys increased linearly with 304CS amount and were four times higher at 20% additions.

SLM allows the challenging fabrication of FeSi parts containing a high amount of Si, optimal for soft magnetic applications, but prone to cracking because of Si embrittlement. Process characteristic features seem to affect the microstructure beneficially as detrimental ordering phase transformations are suppressed, which could be exploited in the future for the production of magnetic components. Furthermore, it is shown how heat treatments can be used to change grain size, ordering state and residual stress level. Ordering can be assigned to DSC curves in two distinct features (**Figure 3**), a first order exothermic transformation peak around 520°C (disorder-order) and a second order endothermic transformation starting from around 825°C (order-disorder). Additionaly, the effect of hardness on ordering and the effect of heat treatments on microstructure were deeply studied.

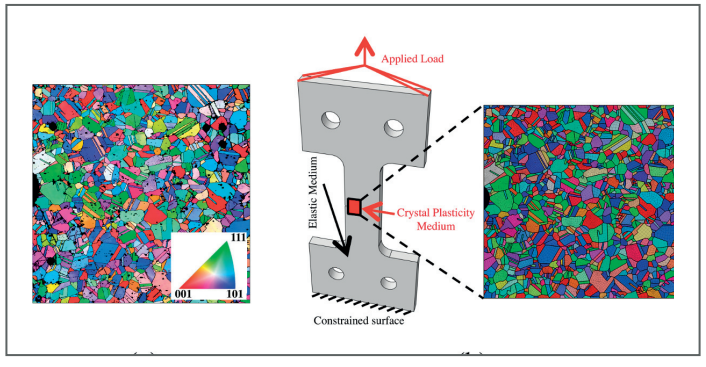


3. Representative DSC heating curve of Silicon-rich Fe-Si as built by SLM. Ordering transformations can be assigned to two distinct peaks.

INVESTIGATION OF MICRO SCALE BEHAVIOUR WITH CRYSTAL PLASTICITY: A STUDY OF HAYNES 230

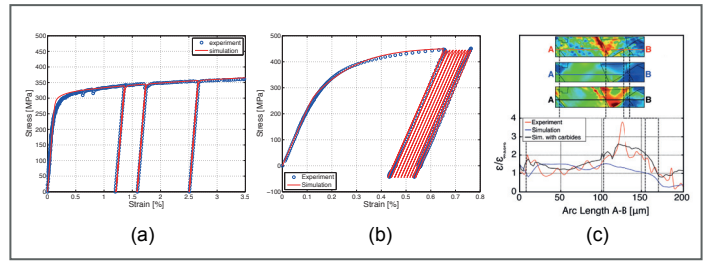
Luccarelli Pietro Giovanni – Supervisor: Prof. Stefano Foletti

Nickel based super-alloys are currently used in gas turbine and aero engines thanks to their excellent mechanical and chemical properties at high temperatures. Components like turbine blades, which are usually made out of single crystals, require high fatigue and creep properties since they undergo extreme mechanical loads and high temperatures over long time, this makes Ni-based alloys the main considerable option for those applications. Same goes for polycrystalline media, which, thanks to their excellent resistance to high temperature and corrosion, are preferable for components which work in harsh environments, like combustion chamber of gas turbine. Phenomena like strain concentrations, local damages and crack propagations are strongly influenced by the material microstructures (**Fig. 1a**). The description of these materials microstructural behaviour through finite element models, which account for crystal plasticity formulations, may help in their design and application. Literature shows many works on crystal plasticity simulations, but they usually rely on experiments only for macroscopic answers; the local anisotropic behaviour is not directly compared with the one obtained from the experiment itself. The link between real local behaviour, measured via digital image correlation technique, and crystal plasticity finite element simulations is still an open field which can be used to corroborate models and acquire information about the micro scale that an experiment alone cannot reach. The thesis applies a crystal plasticity code to reproduce and study further the microstructural behaviour of a Ni-based alloy, Haynes 230. Experiments are discussed as a start for models development and as a comparison for numerical results, on both macro-scale and micro-scale. This comparison on local predictions is used as a tool to validate the adopted crystal plasticity model, whether it is used to simulate cyclic loadings or crack propagation. In the first case the model may predict where a crack would nucleate, due to stresses and strains concentrations. In the second case, with models embedding an existing crack, it may predict which are the driving forces that make the crack propagates.

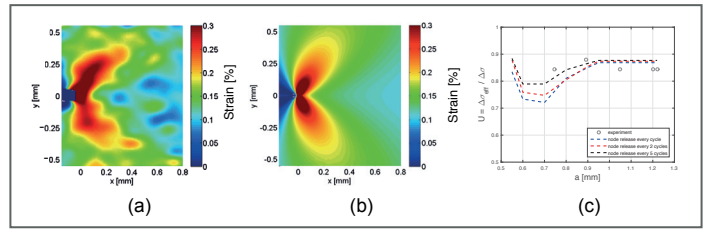


1. a) Example of a microstructure obtained by EBSD on Haynes 230; b) Example of a polycrystalline model created to simulate crack effects

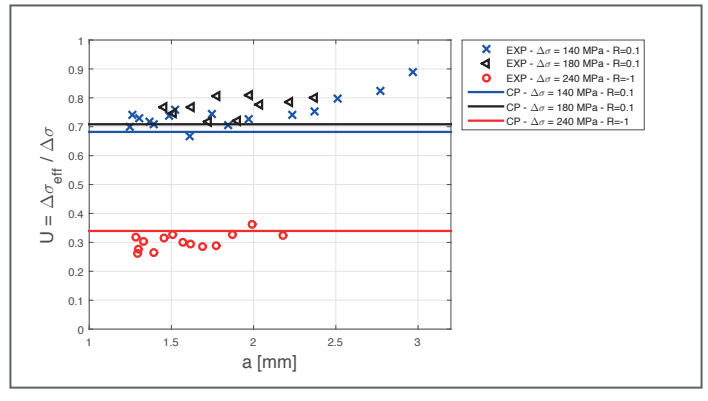
The simulations of real experiments require the definition of geometries and loads/constraints for each model (Fig. 1b): the first are defined according to the observed microstructure, the second, with the loading conditions too, are chosen to best reproduce the loads that the represented portion of material undergoes during the test.
The first part of the work concerns the evaluation of the constitutive model parameters; they are determined by the analysis of several tensile test conducted on single crystals. Then, those very parameters are used to simulate polycrystalline specimen tests. Simulations of monotonic and cyclic loadings brought to an excellent approximation of the macroscopic answer of the material to the applied loading condition, a good agreement on stress-strain diagrams (**Fig. 2a-2b**) is found. The analysis of strain localizations (**Fig. 2c**) compare the experiment, a simulation which accounts only for grains geometries and orientations and a simulation which considers the presence of carbides inside the crystal matrix. The comparison of the three trends shows good predictive capabilities of the model in capturing the strain field.
The first simulation of fatigue crack growth involves a single crystal specimen. The numerical results are compared with the experiment in terms strain field extension ahead of the crack tip and prediction of the stress corresponding to crack opening, the comparison involves different strategies of crack propagation using the node release technique. The prediction results (Fig. 3) on both the strain field extension (**Fig. 3a-3b**) and opening level trend (expressed in term of stress reduction factor) show good agreement.
The second simulation of fatigue crack growth considers randomly generated polycrystalline specimens. This group of simulations involves the prediction of the crack opening



2. Comparison between experiment and simulation results: a) Tensile test's Stress-strain curves; b) Cyclic test's stress-strain curve; c) Strain localization over an extracted region and analysis of the strain trend along a defined arc AB



3. Single crystal fatigue crack growth analysis: a) Experimental strain field at the crack tip; b) Simulated strain field at the crack tip; c) Crack-Opening stress level trend, comparison between experiment and simulations



4. Polycrystal fatigue crack growth analysis: comparison between the crack-opening stress levels obtained with experiments and simulations under three different loading conditions

level considering three different loading conditions (Δσ = 140 MPa at R = 0.1, Δσ = 180 MPa at R = 0.1, Δσ = 240 MPa at R = -1). The results of this last part of the work listed in **Fig. 4** in terms of stress reduction factor against crack advancement: the predictions are able to capture the experimental observations.

DESIGN, DEVELOPMENT, AND ENGINEERING OF A BENCH FOR TESTING LOWER LIMB PROSTHESIS, WITH FOCUS ON HIGH TECHNOLOGICAL SOLUTIONS

Marinelli Cristiano – Supervisor: Prof. Ferruccio Resta

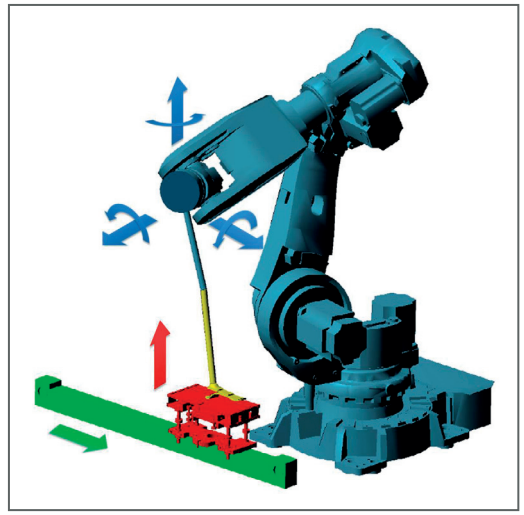
This research topic deals with the development of a bench for testing lower limb transfemoral prostheses, especially modern ones. The idea of developing such a bench was established after a careful evaluation of the requirements and test methods defined by the International Standards Organization to assess the conformity of the mentioned devices. These standards merely identify structural tests to verify that the prostheses, and their individual components, are able to ensure adequate strength properties during their use.
As a consequence, they are not suitable for assessing the functional performance of the prosthetic devices, that is, the ability to assist the amputee while walking. Standards limits are even more evident when considering that, in the recent past, the technological advancement mostly concerned the possibility of integrating ever smaller and more powerful electronic components instead of new materials and topologies. For instance, the knee prosthetic joints currently on the market guarantee maximum yield by means of sensors and actuators that allow to adjust in real-time the physical characteristics and thus the response of the device itself. Meanwhile, researchers are developing novel active devices for restoring many locomotive functions corrupted by the disability, such as sit-to-stand maneuvers, stair/slope ascent ambulation, as well as level walking. However, a prosthesis having such characteristics is far from being realizable in short time. On the one hand, developing a commercially viable active prosthesis that is humanlike in its weight, size, strength, and impedance, while still being energetically economical and noise free, is a challenging design problem. On the other hand, suitable development and verification methods for assessing the functional properties of the prostheses are missing. The need to perform this kind of test is not recent, as a matter of fact several solutions have been proposed in the literature. Among these, in-vitro prostheses experimentations demonstrate several advantages over in-vivo ones in terms of reliability, versatility, and safety. It is therefore foreseen that robotic testing will play a greater role than human gait trials in the development process of prosthetics. However, no system is yet able to completely achieve the aforementioned purpose, to the best of the author's knowledge. According to these considerations, in the present work an innovative in-vitro test bench for assessing the functional properties of transfemoral prostheses is developed. In particular, the definition process is performed in order to overcome the three main significant challenges/limitations of the current gait simulators:

- operating at physiologically correct velocities;
- applying full scale ground reaction forces;
- simulating motion in space, i.e. in three dimensions.

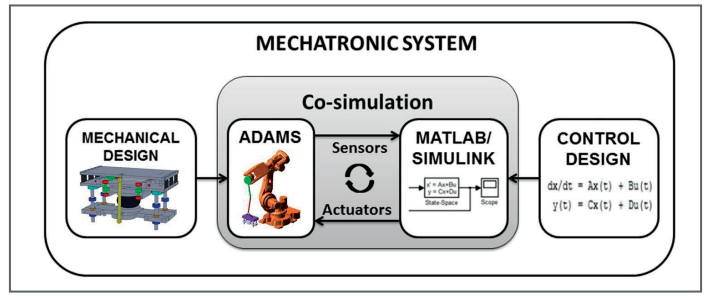
To this end, the kinematic and dynamic data obtained during a gait analysis session are used to:

- define the mechanical architecture of the system;
- identify the essential components and verify their commercial accessibility;
- develop the custom made parts which are not yet available on the market.

At the end of this procedure, the gait simulator exhibits 8 DOFs and is made of two main subsystems with 6 and 2 DOFs. These are respectively used to replicate the series of motion patterns performed by the residual segment of the limb and the loads acting on the prosthetic foot due to reaction with the ground. The first task is realized by means of a six-axes industrial manipulator having suitable



1. Overview of the system mechanical architecture



2. Schematic representation of the co-simulation model

motion and payload capabilities and controlled in terms of position during the entire gait cycle. On the other hand, the contact forces are reproduced through an innovative custom made force plate, controlled both in terms of force and position, whose longitudinal and vertical progression are respectively driven by means of a linear guide and an active air spring. Finally, specific mounting devices are designed to accommodate the aforementioned units and the prosthetic specimen under test. A representative picture of the bench is shown in figure (**Fig. 1**). Once defined the mechanical architecture, the proposed solution is analyzed by performing numerical simulations and experimental test in order to:

- develop specific control logics;
- define strategies for automatizing the test procedure;
- evaluate the merits and the limits of the proposed solutions.

The achieved results support the validity of the design choices. In particular, the usage of a 6-axis commercial robot and of an air spring for reproducing respectively the movements of the hip and the vertical force component is innovative as well as successful. The proposed solution might therefore be applied in the design and development process of the lower limb prostheses in order to:

- assess the functional performances of different lower-limb prostheses (especially modern ones);
- make comparison between them;
- support industries in the design and development of more powerful prosthetic devices;
- satisfy the demand of more functional lower limb prostheses by amputees and restore their full rehabilitation.

DEVELOPMENT OF WIDE SPECTRUM ENERGY HARVESTING DEVICES

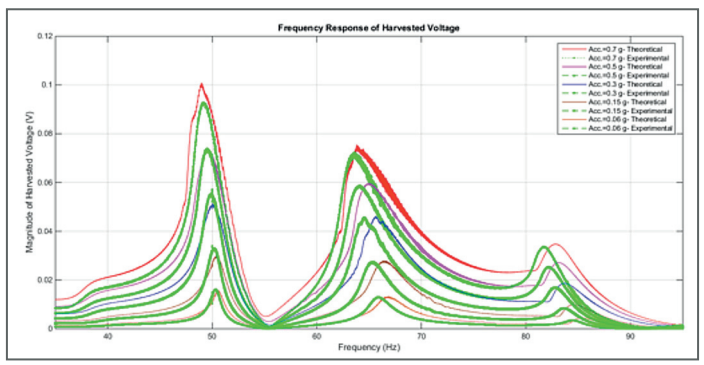
Mehdipour Iman – Supervisors: Prof. Francesco Braghin, Prof. Nora Lecis

Outstanding developments in wireless sensor no des (WSNs) technology for collecting data by numerous sensors embedded in the surroundings is the beginning step of founding smart cities. Providing the energy sources for sensors deployed in remote and difficult to access locations is one of the big challenges of this technology. Supplying power from the ambient source of energy for these devices is an interesting solution. Among several ambient energy sources, mechanical vibration energy source is more talented for energy harvesting. Piezo electric transduction is a promising mechanism for vibration-to-electricity conversion. Additionally, due to high energy density and low fabrication cost, piezo electric ceramic materials are preferable to apply in energy harvesting devices. As far as, most of the ambient vibration sources are in low wideband frequencies, designing the broadband harvester to cover some parts of the ambient frequency bandwidth is an attractive subject for investigation.

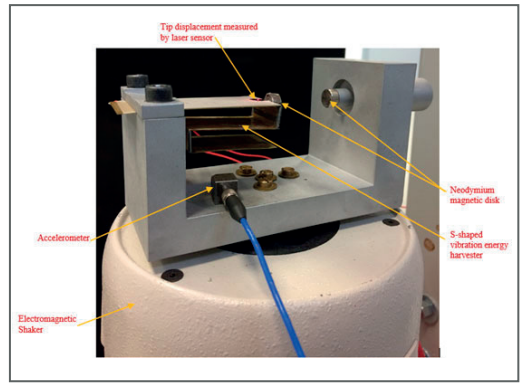
In the present work, by considering the broadband techniques for energy harvesters, a new configuration for broadband harvester is proposed. It is a multi-modal cantilever harvester with three flexible beams those are connected at the end by rigid parts and shaped the S letter. This S-shaped structure with single bimorph patches on the clamped beam is able to create several low closed natural frequencies with almost the same mode shapes at the first three modes without strain nodes. First, the theoretical model of the structure for obtaining natural frequencies and mode shapes is derived by considering both longitudinal and transversal vibration of the structure. The analytical model of the proposed structure is derived to calculate natural frequencies and mass-normalized mode shapes. The exact solutions of eigen problem are presented and compared with the results obtained by FEM model. The results endorse the validity and accuracy of the analytical model for a further analysis of the structural behavior of the model.

$$\ddot{\eta}_r + 2\xi_r\omega_r\dot{\eta}_r + \xi_{rn}\dot{\eta}_r|\dot{\eta}_r| + \omega_r^2\eta_r + \sum_{j,k,l=1}^{N}\alpha_{rjkl}\eta_j\eta_k\eta_l - \left(\chi_r + \sum_{j,k=1}^{N}\varphi_{rjk}\eta_j\eta_k\right)v = \sigma_r a_{ex}$$

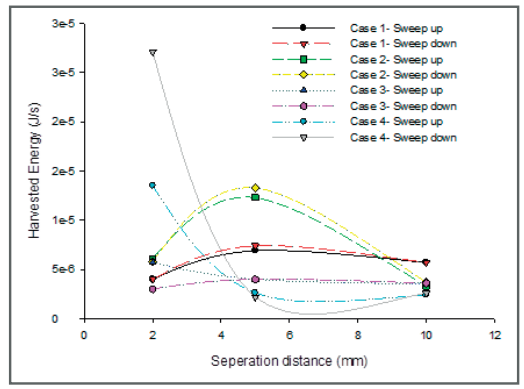
$$C\dot{v} + \frac{1}{R}v + \left(\kappa_r + \sum_{j,k=1}^{N}\beta_{rjk}\eta_j\eta_k\right)\dot{\eta}_r = 0,$$



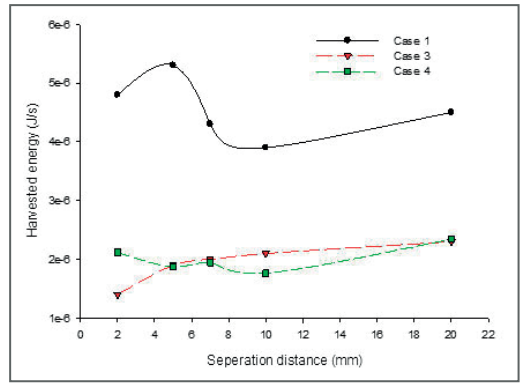
1. Comparison of experimental data with theoretical model for different amplitudes Magnetic interaction nonlinearity is an intentional nonlinearity that imposed to this harvester to create softening and hardening by adjusting the magnetic force. Interestingly, by increasing the repulsive force, the harvester experiences both the softening and hardening and its efficiency is higher when softening happens.



2. Photograph of the tested prototype.



3. The rate of harvested energy versus separation distance of two magnetic disks under harmonic base excitation.



4. The rate of harvested energy versus separation distance of two magnetic disks under random base excitation.

Then, the distributed-parameter electromechanical model for the simple beam is developed for the S-shaped harvester with a single bimorphed patches. Moreover, closed form expression for harvested voltage and power are extracted for the first three modes. Validated results with experimental data confirmed the accuracy of the theoretical model and its reliability for further investigation.

Next, for the high amplitudes of excitation, the prototype is tested experimentally and it validated the improved theoretical model for justifying the softening effect at resonance frequencies. The results approved that softening could considerably increase the frequency bandwidth of this multi-modal harvester.

Last but not least, internal resonance effects for this nonlinear multi-modal broadband harvester with commensurable natural frequencies is investigated for both harmonic and random base acceleration. The results confirmed that appearing internal resonance could strongly improve the efficiency of the harvester in harmonic base acceleration. In contrast, for random base excitation, it was not so supportive of efficiency improvement.

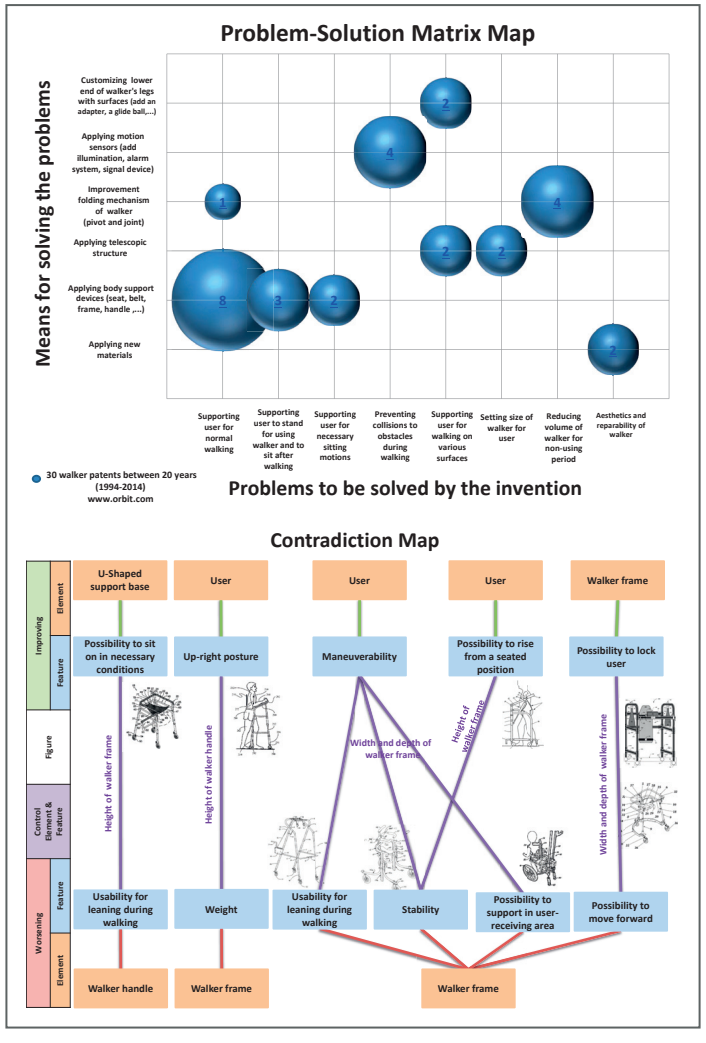
TABLE 1. THE FIRST THREE NATURAL FREQUENCIES FOR DIFFERENT CONFIGURATIONS OF S-SHAPED HARVESTER

Case	Geometry	Natural frequency	f1 (Hz)	f2 (Hz)	f3 (Hz)
1	L_1=48 mm , L_2=40 mm , L_3=40 mm, h_2=2h_3	f_1, f_2, f_3	50.45	66.46	85
2	L_1= 48 mm , L_2=42.5 mm, L_3=56.8 mm, h_2=2h_3	f_1, 2f_1, f_3	29.31	60.73	77.97
3	L_1=48 mm, L_2=42.5 mm, L_3=48 mm, h_2=2h_3	f_1, f_2, 2f_1	38.17	59.89	76.91
4	L_1=48 mm, L_2=42.5 mm, L_3=40 mm, h_2=h_3	f_1, f_2, 2f_1	52.5	66.6	106

IMPROVING IDEAS NOVELTY BASED ON OTSM-TRIZ MODEL OF CONTRADICTION

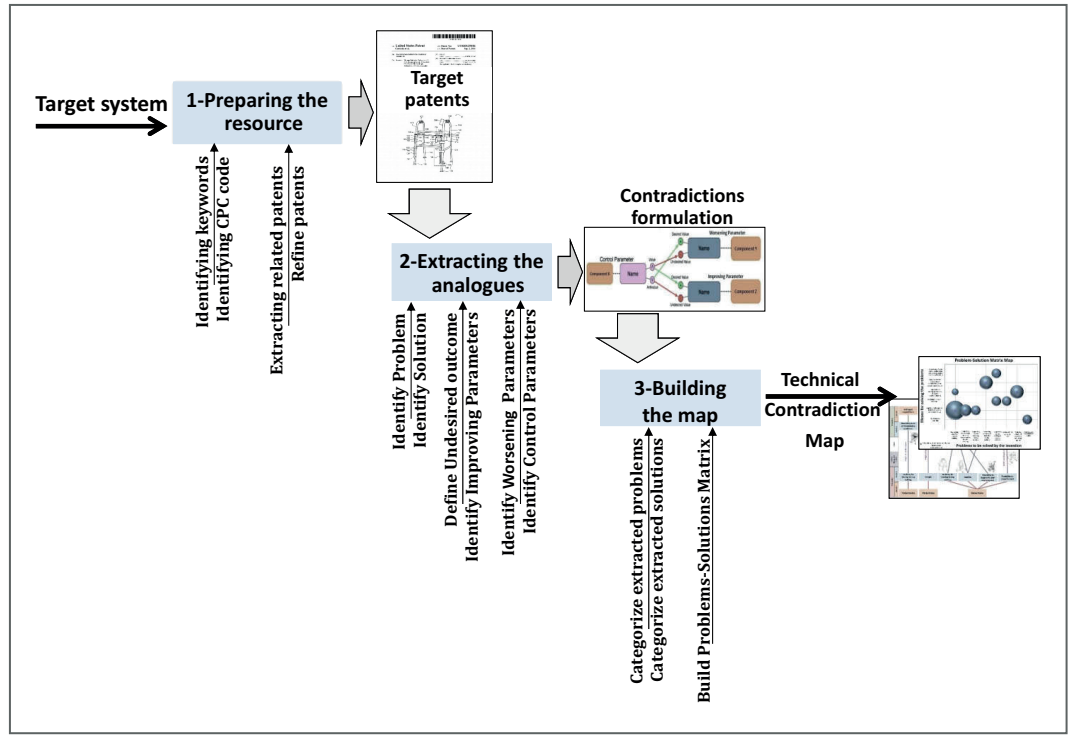
Parvin Mehdi – Supervisor: Prof. Gaetano Cascini

This study is interested in finding and using non-obvious novel ideas from patents of a particular system for improving the patentability of a new invention generated by R&D engineers in SMEs. So the contribution of the current research is an improved Patent Map (Technical Contradiction Map) to support the patentability of generated ideas. Similar to each Matrix Map, three main stages must be planned and followed for building the Technical Contradiction Map. To cover all these three stages, a simplified procedure is developed that is shown in **Figure 1**.



1. Simplified procedures for building a Technical Contradiction Map

The map's usability was estimated based on the collected data in the first experiment. In this experiment, four different methods were applied. Among the four methods, the Technical Contradiction Map provided the highest effectiveness in Novelty and Quantity of generated ideas. Besides the highest effectiveness of the Technical Contradiction Map in comparison to other methods, the estimated coefficient for this one is the only significant coefficient in this regression. The tests based on the F-test statistic also confirmed



the highest effectiveness of the improved version of Technical Contradiction Map. Although Novelty is the main interest of this study, this study's estimates and hypotheses tests also supported the effectiveness of the Technical Contradiction Map compared to other methods regarding Quantity and Variety.

Respectively, for the second experiment, the allocating processes for each group and teams have been done completely at random; no systematic selection regarding their gender, age, education, degree and their knowledge in patent analysis took place. As it can be expected, the estimated results based on being able to repeat the procedure was very close across the different groups. In fact, this experiment verifies the replication capability of building the map; if one uses the same method, conditions and equipment explained in this research, the same results will be obtained.

2. Technical Contradiction Map

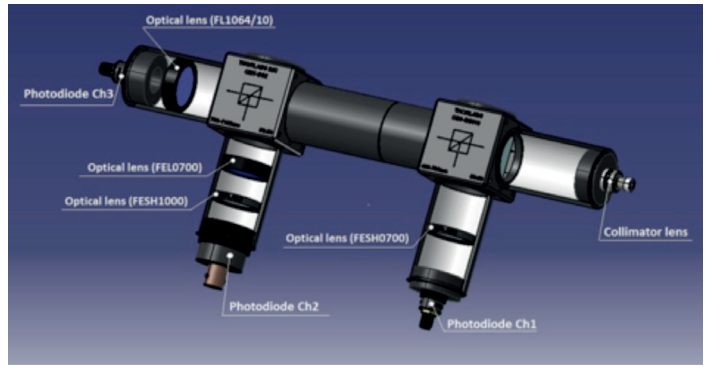
MONITORING OF FIBER LASER WELDING ON TI-6AL-4V BY SPECTROMETER AND PHOTODIODE IN DIFFERENT CONFIGURATIONS TOC, COAXIAL, AND LATERAL

Reshad Seighalani Kambiz – Supervisor: Prof. Barbara Previtali

Co-Supervisor: Prof. Bianca M. Colosimo

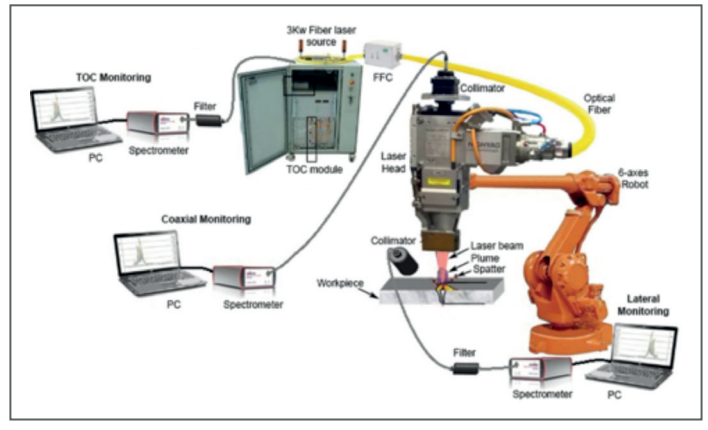
Due to the application of Fiber Laser Welding (FLW) on Ti-6Al-4V for aeronautical industry and the stringent quality standards in this field, developing on-line monitoring system is so crucial to detect process variables and imperfections with high sensitivity. For this reason, in this thesis FLW monitoring tests on Ti-6Al-4V in both the reference and the disturbed weld conditions were carried out in order to investigate, compare, and find the best possible results by using different sensors, configurations, and analysis approaches.
In FLW, the main process parameters are the laser power, shielding gas flow rate, focusing position, which any drift of the mentioned variables from the optimized condition causes a weld defect. In an auto-welding system, the on-line monitoring of the welding quality is very important to avoid weld defects. Therefore, the correlation between signal characteristic with the main process parameters and physical defects were the main aims of this thesis for each configuration and sensor. The monitoring strategies employed in this thesis include Optical Emission Spectroscopy (OES) and Optical Emission Monitoring (OEM) in the three different configurations, TOC (as a novel monitoring position), coaxial, and lateral. The optical benches for both sensors were designed and developed on the reference condition. In figure 1, the frame of developed optical bench designed for OEM is shown. In addition, the schematic view of the monitoring experimental setup in three different configurations for OES is presented in figure 2. The experiments were conducted based on varying the main process factors comprised of the laser power, the shielding gas flow rate, and the beam focus position into two levels and full factorial design to simulate weld defects. Therefore, initially effects of the above mentioned process parameters on the welded samples were investigated based on their geometrical and integrity aspects. Then, different analysis methods were used to distinguish any drift on process variables in the three different configurations and two monitoring strategies. The results were compared to find the best analysis and configuration for each monitoring strategy. Finally, the acquired signals were correlated to the main weld quality parameters to estimate the quality factors through OES and OEM in different ranges.

The comparison of results calculated by different analysis approaches and configurations in a fixed monitoring strategy showed that a proper choice of the monitoring configuration could enhance the fault detection performances. It was found that by applying Principle Component Analysis (PCA) on the normalized spectra in OES any drift from reference condition could be easily distinguished. To achieve this goal, one or combination of PC scores depending on the used configuration could be selected. Thus, PCA as a more efficient method could be proposed to control the main process variables during OES of FLW on Ti-6Al-4V. In OES the best monitoring configuration was the TOC configuration. For instance, the first principle component scores as an indicator in the TOC configuration with relatively high R^2-adj (79.3%) could detect all of the process variables.
In OEM by using VIS channel in lateral configuration, all of the process parameters could be recognized with high R^2-adj (more than 94%) if each of the statistical indicators, the mean, the standard deviation, or the kurtosis, were applied. Through combinations of two channels comprised of VIS or NIR with the laser channel



1. The frame of developed optical bench designed for OEM

in the coaxial configuration, all of process parameters could be detected. It would be with relatively high R^2-adj (more than 72%) if the standard deviation of signal was used. This result could be achieved if two statistical indicators, mean and standard deviation, were applied in the TOC configuration and VIS channel.
A threshold value could be defined in both OES and OEM strategies in two configurations, coaxial and TOC, which can recognize the transition between partial and full penetrations. Different levels of oxidation could clearly be recognized in OEM through threshold values of the standard deviation in the lateral configuration and NIR channel. Furthermore, there was high



2. The schematic view of the monitoring experimental setup in three different configurations (Coaxial, Lateral, TOC) for OES

minimum optical components were used, and photodiode sensor that captured the emission light with high sampling rate and consequently high time resolution. By using the aforementioned combination system, all of the process variables could be recognized easily with high R^2-adj (more than 94%). These abilities, to recognize any drift of process parameters strong quadratic association between the kurtosis of NIR channel and the area of porosity in the coaxial configuration (for OEM).
To conclude best combination of a monitoring position and a sensor was achieved by lateral configuration where the and imperfections in an online monitoring step, present a robust, accurate, and high-speed response system for monitoring. It can prevent destructive tests that are expensive and time-consuming.

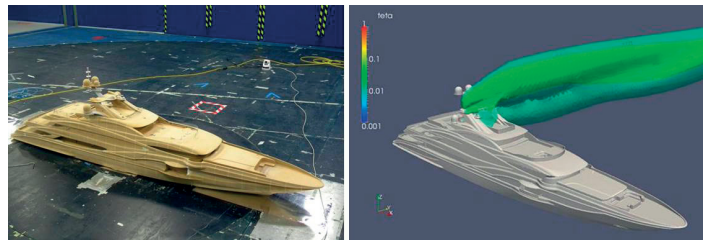
SUPER & MEGA YACHT'S AERODYNAMIC, ON-BOARD COMFORT AND POLLUTANT DISPERSION ASSESSMENT METHODS: WIND TUNNEL AND OPEN-SOURCE NUMERICAL DESIGN TOOL

Robustelli Fabio Cristiano – Supervisor: Prof. Marco Belloli

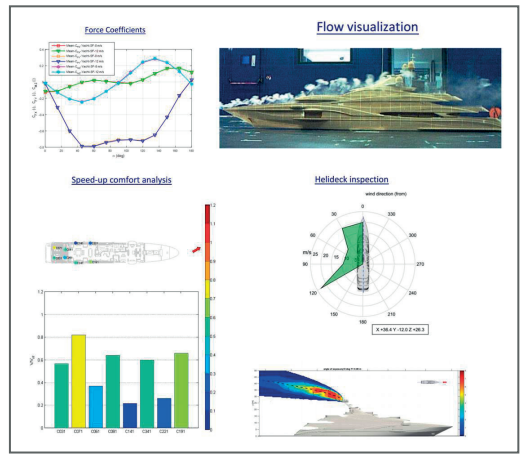
Comfort on board a luxury yacht is obviously a key feature in all its aspects, like ship motions, noise and vibrations, windage and exhausts gases issues. Larger main dimensions, superior comfort requests and higher manoeuvrability characteristics focus mega-yacht designer attention towards hull and superstructure aerodynamic performances.

1. Superyacht at mooring - stern view

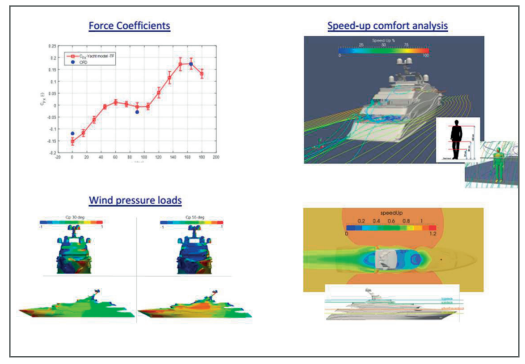
Windage evaluation of very high superstructure, aerodynamic load assessment, and accurate air flow simulation are considered very important in the design procedure to get optimal layout and opening position. Moreover they are used to precisely sizing thrusters horsepower requirements and Dynamic Positioning Systems. The lack of data concerning the peculiar mega-yacht forms and the result accuracy requested lead to set up a method for the aerodynamic evaluation through scale model wind tunnel tests or numerical simulations (CFD). Wind tunnel tests are asked more and more frequently by designer and surveyors and are considered a fundamental reference for any further CFD simulation. Within this work the experimental and numerical methodologies developed at Politecnico di Milano Wind Tunnel in order to assess mega-yacht aerodynamics in terms of aerodynamic loads, comfort analysis, pollutants dilution, re-ingestion and helideck analysis using wind tunnel tests are described as well as the numerical models developed by the author aiming to build a more practical design tool helping yacht designers to improve the whole design process.
In particular, the dispersion of exhausts around the yacht is a complex issue that may be accurately investigated using a computational model. The proposed CFD analysis is firstly conducted through a commonly used commercial code to fix the main modelling issues: several different approaches are investigated for modeling the dispersion of exhaust gas around the yacht aiming to find the best compromise in terms of accuracy and computational cost.
In addition effects of temperature and gravity on the pollutant dilution are investigated and discussed. The main challenging part of the work regards the further implementation of same approaches in the open-source fluid-dynamic framework OpenFOAM taking into account the main features of the interaction between the yacht aerodynamics and the pollution emission.
Numerical results agree very well with results obtained with commercial software and are validated against wind tunnel tests. The key points of this work concern several aerodynamic issues, as it represents a clear method of analysis for comfort on board a luxury yachts in terms of both aerodynamics and pollutant evaluation considering also the ability to perform helideck certification. It would establish a fundamental reference in literature. Finally the open-source numerical tool would be a powerful instrument for yacht designers allowing to save costs and to perform a more efficient design process obtaining even more excellence products.



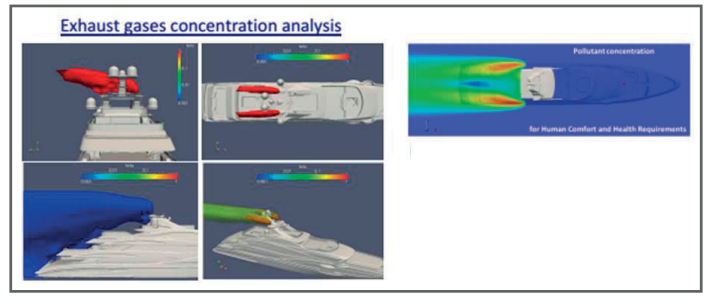
2. Wind tunnel scale model of Benetti FB262 mega-yacht and CFD full scale model



3. Wind tunnel test results: a powerful instrument for design purposes



4. CFD results: a more efficient and powerful tool for design and optimization



5. CFD results: a more efficient and powerful tool for design and optimization

SERIOUS GAME FOR THE NEXT GENERATION OF TECHNICAL SYSTEMS:
TO IMPROVE THE CAPABILITIES OF R&D ENGINEER IN PROPOSING IDEAS FOR THE NEXT GENERATIONS OF TECHNICAL SYSTEMS

Saliminamin Sara – Supervisor: Prof. Gaetano Cascini

Engineering design has to support R&D engineers in designing the next generation of technical systems to make companies ready for the radical changes in the market. Developed technology forecasting and design methods are not effective for long-term design and this task is mostly followed in typical design sessions by focusing upon improving the characteristics of design proposals. Effective design stimuli in the form of design heuristics (consisted of design precedents and strategies) are used to improve characteristics of design proposals. There is no direct research in the field for the next generation of technical system. Therefore, the ultimate objective of this research is to improve capabilities of R&D engineers in proposing the concept of the next generations of technical systems. As the main novelty, this research approaches such this design task through developing a special serious game for designers called "Techno-shift".

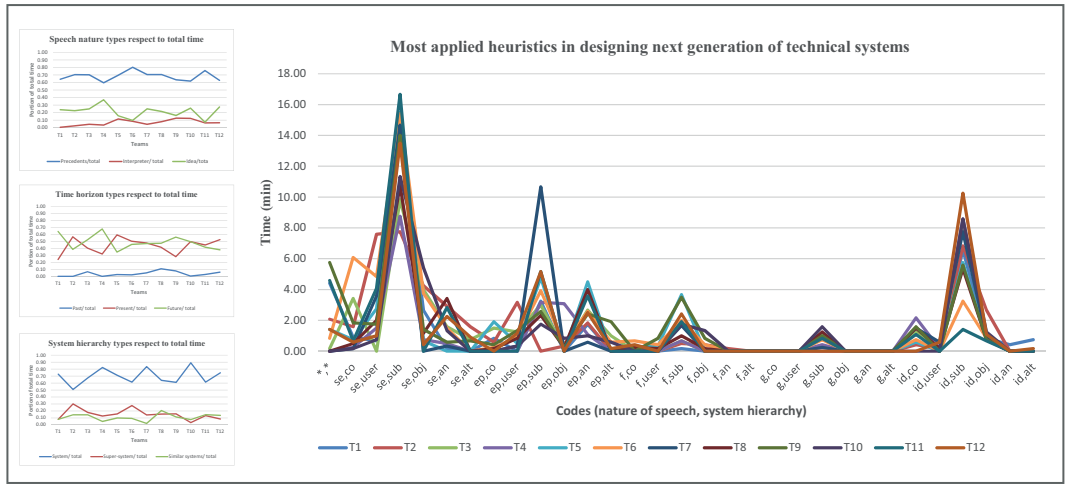
To develop the mechanics of the Techno-shift game, an empirical study was done through protocol analysis to highlight the skills of R&D engineers in exploiting their knowledge and experiences in the form design heuristics. A set of criteria for assessing candidate ideas, a coding scheme to highlight the used heuristics, and a set of stimuli for improving the R&D engineers' performance, became the three main other innovative features of the research.

Study the performance and skills of R&D engineers in a 45-minutes design session for designing the next generation of technical systems, show on average 3.9% of the total generated ideas, are ranked as the candidates for the next generation of technical systems.

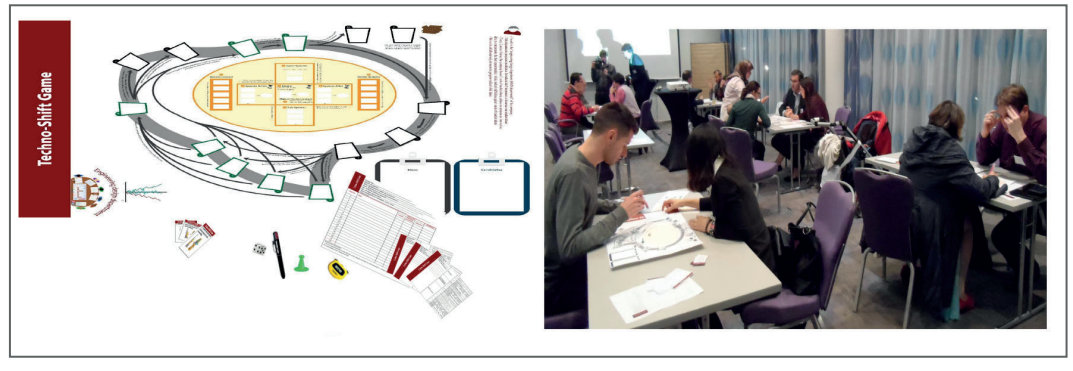
Nature of speech, time horizon, and system hierarchy are the dimensions of developed coding scheme which 90 combinations can be constituted as design heuristics by considering their sub-classes. The teams spent 20% of the time to search promising spaces and resources (episodic precedent), 50% to analyze the discussed resources (semantic precedent), 10% to discuss task requirements, and finally 20% to idea description. As the dedicated time to the present and future in the scope of time horizon, were equal and almost half of the whole time, this dimension considered natural in the combinations of heuristics. By discarding the sub-classes of time horizon, 30 possible couples of moods of nature speech and system hierarchy could be studied. Among the 30 options of possible couples, only 15 of them are considered as the active skills of R&D engineers in designing the next generation of technical systems. Studies show the effective skills which are the codes before the candidate ideas in the protocols are the same codes as active skills with different sequences and orderings.

Pictorial presentation of trends of evolution of some technical systems, abstract of patents related to the function of target system, and an engineering procedure for designing the next generation of technical systems are the three stimuli which are developed and studied in the scope of this research. The study shows trend compare to other stimuli and control group is more effective in influencing quantity, technical plausibility and relevance of ideas positively, patent is more effective in increasing quantity of candidate ideas and none of stimuli are effective in increasing the novelty of ideas compare to the control group. Engineering procedure increased usage of effective codes by R&D engineers but it is not effective in guiding them to generate candidate ideas.

Based on the results of performed protocol analysis, the Techno-shift game was developed. The game mimics the production line of industries and starts with the 'Table of resources' and follows through the 'Idea generation line', where the player can propose new ideas by means of the 'Think stations and design heuristics', the 'Tips and tricks', the 'Examples for creativity stimulation' and the 'Idea cards'. Eventually, the game finishes by assessing the results through completing the 'Score card'. Effectiveness, usability and robustness of the proposed serious game were studied in an empirical study in 5 parts; one part for the control group which the participants generated ideas in a 45-minutes normal design session and four other groups that different players in profiles applied the Techno-shift game in same time for same and different target systems respect to the control group. R&D engineers considered as the main target players for the two groups and the profile of players expanded to master engineering students and problem-solvers for the two other groups. The results show, although productivity in terms of total number of generated ideas was decreased to almost half for four other groups compare to the control group, but the effectiveness in terms of number of generated candidate ideas are increased to 7 to 9 times. Also the other indexes show that players are able to apply the games' rules and less than 40% misunderstanding or misinterpretation are observed for applying heuristics and assessment criteria. Finally, there is no evidence to reject the robustness of the game, as the results of playing various versions of the game are not significantly different.



1. The observed heuristics in R&D engineers' thinking path in designing the next generation of technical systems



2. Overall image of Techno-shift game

ITALIAN HIGH SPEED RAIL DEVELOPMENT: AN INVESTIGATION ON TRAIN-INFRASTRUCTURE AERODYNAMIC INTERACTIONS

Somaschini Claudio – Supervisor: Prof. Daniele Rocchi

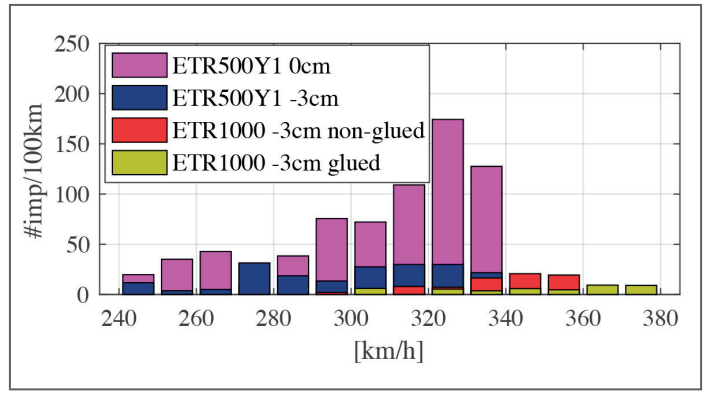
In the last forty years, railway transportation in Europe changed considerably, with the development of high speed lines and trains with speeds up to 300km/h and higher. Following this trend, since train aerodynamic effects, on first approximation, increase with the square of the train speed, the interest in trains aerodynamics has grown exponentially. Moreover, if on the one hand, existing aerodynamic problems intensify with the increasing speed, on the other, new issues appear approaching or exceeding 300km/h. This thesis deals with two of these issues, the ballast lifting phenomenon and the overpressures in tunnel, since, due to the Italian high-speed line characteristics, they represent the most challenging aerodynamic issues considering the train speed increase.

This PhD thesis focuses on a series of experimental tests carried on different parts of the Italian HS line, measuring on board and at trackside, and recording data for both testing trains and commercial ones that allowed to better investigate these two problems.

As regards the ballast, since there is not a European or Italian standard and, moreover, since the Italian HS lines are all made up of ballasted tracks, a lot of work was required. The aim was clear: to reduce the risk of ballast particles lifting for a new train running on the Italian HS line at 350km/h without the ambition to fill the gap in the standards drawing results valid for any train-infrastructure configuration. Following the different European projects that have been conducted on this issue, a series of experimental tests were carried out at trackside, on board and within the wind tunnel, investigating the flow characteristics in the underbelly region for different track-train configuration together with the forces acting on the upper ballast stones. In line with the experience gained during the AOA project, an experimental campaign was carried out measuring the flow fluctuations induced by the Italian HS trains on differently prepared stretches of the line. Later, experimental tests were performed on a full-scale track section in the Politecnico di Milano wind tunnel. Using an obstacle close to the track and a hydraulic actuator under it, it was possible reproduce the conditions measured at trackside in terms of flow speed profile and track acceleration in order to study the threshold conditions of ballast dislodgment for different track configurations. This study showed a weak dependence from the stone acceleration induced by the train passage on ballast lifting while confirmed that the flat shapes of the stones of the upper layer of the ballast bed increase the risk of ballast lifting.

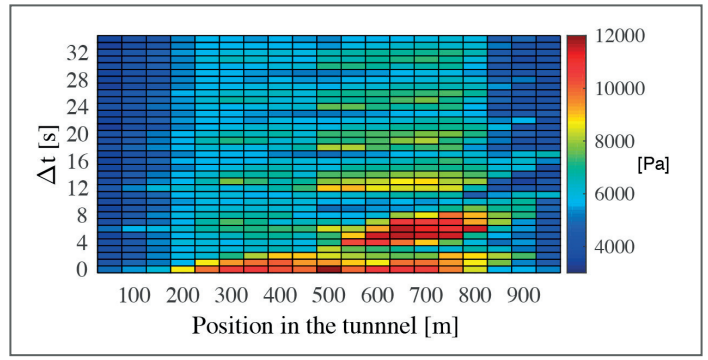
Finally, through an extensive statistical analysis, the actual number of impacts per kilometre was measured with increasing train speed up to 350km/h by means of microphones placed on board refining the AeroTRAIN methodology and comparing different train-infrastructure conditions. For different track configurations it was possible to correlate the flow results with the statistics of the ballast impacts at full scale; although lowering the ballast level of 3cm results in higher speed profiles, the number of impacts was reduced of more than four times.

As regards the overpressures in tunnel, the study was slightly different since this topic is well defined in the European standards as well as the test procedures required to certify a new train. Nevertheless, there is a lack in the literature of full-scale data to validate the numerical codes that are required in the certification process and used in the train structural dimensioning. To this aim, an extensive full



1. Number of detected impacts as a function of the train speed on the HS line To-Mi with all the tested configurations

scale experimental campaign was performed in order to compare the "pressure signatures" of the Italian high speed trains and to validate the numerical codes used to investigate the overpressure in tunnels induced by a critical trains crossing. The results showed that the initial flow speed within the tunnel highly modifies the pressure signature, therefore, a limit value or corrective formula (like one proposed in this work) should be defined in the standard. The validation of a one-dimensional code was performed using experimental results acquired both on board and at trackside in tunnel considering both single train passages or aerodynamic fatigue loads that the train doors have to withstand during a long term operation in mixed traffic. This gave the opportunity to compare the different physical phenomena producing aerodynamic loads on sealed and unsealed trains, increasing the understanding of the pressure wave generation and transmission. The suggested model well reproduces the



2. Simulated MaxΔP as a function of the relative entry delay of two trains and of the position along the tunnel

two trains crossings. Finally, a numerical model, in order to predict the internal pressure of an unseal ed train, was developed starting from the data recorded in a full scale experimental campaign performed on a regional train on the *Direttissima* between Florence and Arezzo. In particular, the analysis was focused on the evaluation of the internal pressure starting from the external one and it is essential in the proposed procedure to define the aerodynamic load spectrum for an unsealed train in a mixed traffic scenario.

DESIGN OF ENERGY REGENERATIVE DAMPER FOR AUTOMOTIVE APPLICATIONS

Todmal Prashant – Supervisor: Prof. Stefano Melzi

Co-supervisor: Prof. Federico Cheli

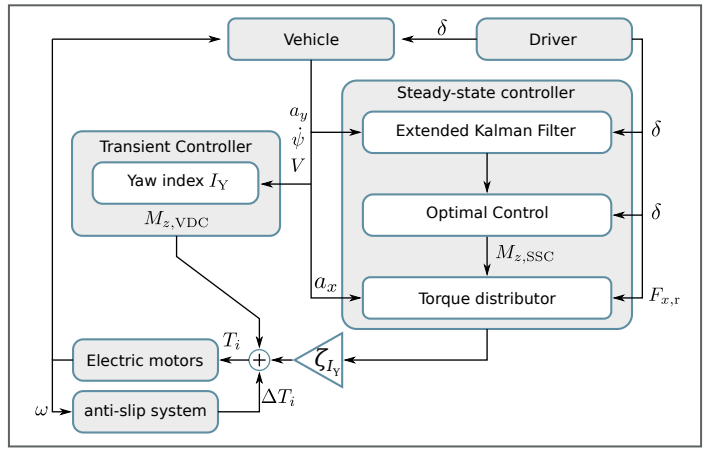
The energy need of the world is increasing over time and conventional energy sources are depleting. More use of fossil fuels increases CO_2 emissions which creates environmental problems. For this reason, we are continuously striving to increase efficiency of the systems and reduce the fuel consumption.
The process of capturing the energy from system environment and converting it into usable electrical energy is known as energy regeneration. Considering case of road vehicles, most of the fuel energy is wasted due to the low efficiency of ICE but, due to the high power/weight ratio of this component, it will still be equipping almost all the vehicles for several years.
One opportunity of energy regeneration in road vehicles is in the suspension system. Suspensions aim at isolating the carbody from the vibrations coming from road surface and improving road handling by ensuring contact between tire and road. In this work design and analyses of energy generative damper are carried out to improve performance of a vehicle suspension system in terms of passenger comfort and road holding with regeneration of energy which is getting wasted in suspension systems. The study is carried out on various types of road surfaces i.e. country road, ordinary road and motorway. The numerical analyses of the system are carried out in SimMechanics® environment. In a regenerative damper mechanical energy of vibration is converted in to electrical energy by using principle of electromagnetic induction and damping effect is achieved as a result of power generation. Combining vibration reduction performance and regeneration of energy to reduce vehicle fuel consumption is the main purpose of this project.
Vehicle industry is growing in the rapid rate; innovative technologies are playing very important role in it. Among all systems in the vehicles, suspension system is one of the most important. We can't imagine a high performance vehicle without efficient suspension system. A key component of suspension system is the damper. To achieve better performance by the system efficient dampers plays an important role. In conventional viscous dampers the energy of vehicle vibration is lost in fluid friction as a heat. Considering loss of energy in the conventional dampers it is very good opportunity to do research work to regenerate this energy. The energy getting wasted in the dampers is basically coming from the fuel. If we can regenerate this energy and use it for vehicle electrical applications the overall efficiency will be improved and size of the electrical generator of a vehicle will be reduced. The theoretical amount of energy available for recovery is as high as 10% of fuel consumption. Also electromagnetic dampers can provide extra advantages in case of semi-active or fully active suspension system as electrical energy is easy to control and process. In the field of electromagnetic dampers lots of research is been going on. Adding work to development of this field is the motivation for this research. In this work design and analyses of energy generative dampers are carried out to improve performance of a vehicle suspension system in terms of passenger comfort and road holding with regeneration of energy which is getting wasted in suspension systems. The study is carried out on various types of road surfaces i. e. country road, ordinary road and motorway. The numerical analyses of the system are carried out in SimMechanics® environment®. In a regenerative damper mechanical energy of vibration is converted in to electrical energy by using principle of electromagnetic induction and damping effect is achieved as a result of power generation. Combining vibration reduction performance and regeneration of energy to reduce vehicle fuel consumption is the main purpose of this project.
The contents of this PhD thesis are mainly included study, design, modelling, analyses and innovation of Electro-Magnetic dampers (EMD). Work is started with the study of past attempts made to recover this energy with energy regenerative dampers. Only 20 % of fuel energy is used for actually moving the vehicle rest of the energy is wasted hence improving fuel efficiency is critical for vehicles. To achieve it energy regeneration from vehicle suspension system is potential solution as the amount of fuel energy getting wasted in suspension system is significant. Development of energy regenerative damper can improve comfort and energy regeneration. As a result of energy regeneration reduction in fuel consumption and CO_2 emissions is possible which can make contribution to reduction of global warming and changes in planetary weather. Car industries can save 75 euros per gram CO_2 of per kilometre of vehicle travel which can help to reduce the price of a vehicle. Fuel saving achieved can reduce cost of fuels for customers too. All this shows that electromagnetic dampers have potential to be used in automotive industry extensively. The content of this thesis could be divided into four major categories: 1) Design and performance analyses of BSEMD 2) Computation of reduction of fuel consumption and CO2 emissions by the use of EMDs 3) Innovative design of CLEMD, its design and analyses 4) optimization of suspension control parameters to improve performance.
Modelling of vehicle suspension system is done in SimMechanics® and Matlab environment. Analysis of vehicle suspension system is carried out with viscous damper. From the analysis specifications required for Electro-magnetic damper (EMD) are found out. These specifications are used in design of BSEMD where design, CAD modelling and Simulink modelling of ball-screw EMD is carried out. Analyses include comparative analysis of power lost in EMD and viscous damper. From the energy modelling carried out the effect of EMD power regeneration and mass of EMD on fuel consumption and CO_2 emission is computed with the help of various missions including NEDC cycle. Here it is found that with on-road vehicles performance of EMD is not enough to reduce fuel consumption as the amount of power available is low because the road is smoother. And also the mass of EMD is critical factor to reduce fuel consumption hence it's needed to be reduced.
To solve these problems two solutions are proposed: 1) Off-road vehicle application to increase power available for regeneration 2) development of innovative crank-lever type of EMD. Analyses of off-road vehicle are carried out to determine reduction in fuel consumption and CO2 emissions by using EMDs with ECE 15 cycle. With off-road vehicles power regeneration and reduction is fuel consumption seems satisfactory. Design and modelling of innovative crank-lever type of EMD is carried out in chapter 6. Attempt with various type of design configurations are considered finally three stage gearbox type of design is finalized as it gives the best performance among all. Matlab modelling for crank-lever EMD is carried out. Weight comparison of various EMDs is carried out and it is found that with three-stage CLEMD significant reduction in weight is possible. CLEMD is able to recover higher power over BSEMD with regeneration efficiency of 87%. The fuel saving achieved with CLEMD is satisfactory. Up to 6 % of fuel energy that is getting wasted can be recovered by using CLEMD for ECE 15 cycle. CLEMD is good alternative to viscous dampers provided that cost of the components is reduced. Analyses are carried which are useful to understand the effect of suspension parameters damping and stiffness on performance of suspension system. Electric motor can also be used to mimic spring effect. Reducing the suspension stiffness by using negative stiffness force provided by the CLEMDs can improve comfort as well as increase power regeneration at the same time. This work is useful for selecting control algorithm for suspension system which can improve power regeneration and comfort at the same time.

INNOVATIVE CONTROL STRATEGIES FOR 4WD HYBRID AND ELECTRIC VEHICLES

Vignati Michele – Supervisor: Prof. Edoardo Sabbioni

In last decades, the research on hybrid and electric mobility has grown pushed by a high request of green transportation. Many powertrain layouts have been designed trying to exploit all the potential of electric motors. Among all the possible layouts, the one that is the most interesting for torque vectoring is represented by four independent wheel drive vehicle. This layout can be realised with onboard motors with driving shafts or with in-wheel motors (IWM), i.e. motors collocated directly inside the wheel. Typically, IWMs have the motor stator that is fixed to wheel hub; the rotor instead is fixed to the rim so that the motor is completely housed inside the wheel. There are several advantages concerned with IWMs: all transmission components can be eliminated. This means room saving, weight saving and less components to take care of and maintain; available space can be saved on-board vehicle which can be used for larger batteries or for increasing comfort of passengers. The main drawback of IWMs is the increase in unsprung masses which means that suspension stiffness has to be properly adjusted in order to maintain vehicle handling and comfort characteristics. The main advantage of IWMs is instead the possibility of independently apply driving or braking torque on each wheel and thus the possibility to design in the easiest way a Torque Vectoring control strategy.
Optimal control theory is the most common approach used in the literature to design torque-vectoring control of IWM vehicles. These kind of controllers have proved to be very effective in improving vehicle handling. However they require the estimation of the actual motion of the vehicle (sideslip angle and yaw rate) and to update the reference-model parameters (such as cornering stiffness) whenever working conditions change (as an example when road adherence conditions change).
It can be argued how this is of concern particularly during manoeuvres characterised by very fast transients, such double lane changes or step-steer manoeuvres.
To further investigate the above mentioned issues in the design of torque-vectoring control of a IWM vehicle, a strategy based on optimal control theory is coupled with a control logic relying upon an index, which is directly related to oversteering/understeering behaviour of the vehicle and it is based only on measured quantities. During the transient parts of a manoeuvre, the control action is mainly decided based on the proposed yaw index, since it does not require any estimators/observers. In steady-state, the control strategy is instead mainly driven by optimal control, whose parameters are updated during transients (where decisions are taken based on the yaw index).
To avoid that torque demanded by the control strategy to a single wheel may exceed the maximum available and prevent wheel spinning/locking-up a torque distributor is added to the control system.
The main scheme of the controller is reported in **Figure 1**. The high-level controller generates a suitable yaw moment in order to control vehicle lateral dynamics. It is made mainly of two contributions:

- a transient controller (dynamic stability control) which relies on Yaw Index IY which is related to the dynamic over/under-steering condition of the vehicle. Yaw index is defined as IY = ay/vx - ψ̇. This index is directly related to time derivative of vehicle lateral velocity. The target of this controller is to increase vehicle stability. It is to point out that this controller does not need any estimation of sideslip angle and, what is more important, of friction coefficient. The only estimation required is longitudinal velocity of the vehicle, which can be roughly estimated from wheels angular velocity.
- a steady-state controller (SSC) that is based on optimal control theory. The steady state controller is coupled with an Extended Kalman Filter, which is used to estimate sideslip angle and the friction coefficient between tyres and road. SSC target is to track yaw rate and sideslip angle references by generating a yaw moment. To generate the demanded yaw moment, torque is distributed among the four wheels accounting for driver's inputs (brake and accelerator pedals) and load transfer due to acceleration. The duty of this contribution is mainly to improve vehicle steady-state handling characteristic.



1. main scheme of the controller

Simulations have been performed in order to evaluate controller performances. The aim is to test controller performances both in transient and in steady-state conditions and with and without coupling with driver. For some manoeuvres, also the effect of friction coefficient variation is analysed.
Simulations results showed that the control strategy can in fact increase vehicle performances in all tested driving conditions. For low lateral accelerations, the active vehicle presents a higher degree of linearity with respect to passive vehicle, this make the vehicle easier and funnier to drive. The controller helps in fact the driver to follow a reference trajectory with smaller corrections on the steering-wheel and with higher cornering performances. For high lateral acceleration, performances of the vehicle are in general increased in terms of maximum lateral achievable acceleration.
In transient conditions, the active vehicle presents in general a smoother behaviour. Oscillations of yaw rate, lateral acceleration and sideslip angle are reduced together with overshoot values. In these high transient conditions, the transient controller by itself gives significant improvements with respect to the passive vehicle. This controller does not need the steady-state contribution and it can give significant improvements if compared with classical brake based control systems. The presented control strategy has also been applied to different powertrain layouts allowed by the use of independent motors. Same performance improvements are highlighted for all the layouts although small differences occur. From simulation results emerges that: four independent wheel drive vehicle seems to be the most performing solution both in steady-state and in transient conditions. Rear independent wheel drive vehicle presents an increase in steady-state performances with respect to its corresponding passive vehicle but is not so effective in damping oscillations during transients, in fact hydraulic brakes intervention on the front axle is needed in critical oversteering conditions. Independent Front wheel drive vehicle is the most improving layout with respect to the corresponding passive vehicle and this makes this layout preferable with respect to other in term of mechanical complexity and probably costs. Plug-in solution for front and rear axles can be an optimal solution for expanding performances of existing vehicles. In particular the front axle with independent motors plug-in solution allows to obtain high benefits for rear wheel drive conventional sport cars in particular in cornering promptness and moreover in enhancing stability.

DEVELOPMENT OF A MONITORING DEVICE BASED ON THE THERMAL EMISISON IN LASER DIRECT METAL DEPOSITION

Zarini Stefano – Supervisor: Prof. Barbara Previtali

Laser Direct Metal Deposition (LDMD) is an additive technology based on the continuous material feeding mechanism. The material is progressively melted with the aid of laser and, layer after layer, is aggregated in order to obtain 3D complex components. Due to the numerous advantages this new approach to building objects is showing, the technology is becoming widely used for a wide range of applications such as Aerospace, Automotive and motorsports, Oil & Gas, Military, Medical and Jewelry. However, the complexity of the overall process, and the need for cross-disciplinary competences, requires the development of new scientific works which touch upon most of the aspects this technology deals with. In order to better understand the overall deposition process, its monitoring represents one of the main targets. The response variables which could be monitored are different. However, monitoring the thermal emission of the process represents one of the most promising responses, as the mechanical proprieties of the material (and thus its metallurgy and the morphology of the deposited layer) are connected to this.

This work represents the development of a monitoring and control device based on the multimode fiber laser architecture. The design of the monitoring and control device is based on Planck's emission law, and the developed system is compared with other temperature measurement instruments such as thermal camera and thermocouples.

The signals deriving from the different instruments show good agreement with each other, as well as correlation with the morphology of the deposited layer. Information deriving from the designed monitoring device is firstly used to understand and select proper process parameters during the deposition of AISI 316, and later to used improve the uniformity of the deposition using it as input for closed loop control over the laser power.

The analysis revealed that, among the different possible radiation bandwidths to be observed, the one that best fits the requirements has a central wavelength of 900 nm and a bandwidth of 40 nm. This, coupled with a silica photodiode, resulted in a sufficient structure to monitor and control the thermal emission in LDMD through the optical combiner.

The design phase was supported by a series of experiments which compared the designed device with industrial systems (thermal camera and thermocouples). It was found that thermal emission of the deposition process perfectly fits the first order model typical of thermal phenomena. Moreover, a linear relationship (R^2_{adj} = 50,0 %) was found between the thermal emission measured with the designed monitoring device and the peak of temperature measured with thermocouples. Similarly, a linear relationship was found between the thermal emission measured with the designed device and layer height (R^2_{adj} = 74,2 %). In addition to these tests, strong similarities were identified between the signal recorded by the designed instruments and the one obtained from the thermal camera. As the analysis carried out to compare thermal emission with layer thickness, signals deriving from the thermal camera and the designed instruments were notably similar to the deposited shape. This analysis once again highlighted the relationship between the two. The controller constants were defined with an experimental approach. In order to avoid the instability of controlled process, the derivative constant T_d is set to zero while, to improve the readiness of the controller, the proportional and the integral gain are continuously varied until controller performances were satisfied. After the testing phase, the designed monitoring and control device was used to understand the deposition under the application of different deposition parameters: laser power "P", feeding speed "v", z increment "Dz" and deposition strategy. The quality of the deposition was measured with different geometrical measurement instruments to understand the overall deposition process. It was found that with power lower than 500 W, and at any tested speed, the energy was not sufficient to allow regular material deposition. Similarly to laser power and feeding speed variations, the deposition strategy has a significant role during the deposition process. These process variations manifested themselves from the thermal emission process point of view. When the deposition process becomes irregular, the thermal emission signal begins to oscillate visibly, highlighting bad deposition. On the contrary, when regular deposition was observed, thermal emission becomes more regular. Moreover, when regular material deposition was observed, the larger the thermal emission intensity, the larger the dimensions of the deposited track (height and width). Stability of the thermal emission of the molten pool was proved to be a sufficient condition for having uniform deposition layer due to heat accumulation. To obtain uniform geometrical proprieties layer after layer, a PID controller over the thermal emission was employed. It was identified a proper set value of the controller (1.2 V) which allows uniform deposited layer to be obtained. With a proper setting of PID set value, process parameters and deposition strategies, the quality of the deposition improved up to 25 times the uncontrolled deposition process (the data considers the internal cilindricity of the deposited cylinder as response variable for evaluation of the deposition quality). When the monitoring and control device was applied for the realization of more complex and large dimensions components its effectiveness was not as significant as when it was used for tuning. More specifically, the main discrepancy was related to the geometrical difference between the geometry used for tuning and the real component. In the first case, the geometry was smaller and thermal drift was achieved earlier in the deposition strategy. Another important aspect to be taken into account in the application of the designed monitoring and control device for the realization of real components is their geometrical shape. It was observed that after sudden trajectory variation, the controller was not able to compensate heat accumulation. This could be related to the fact that the tuning of the controller was done considering the thermal behavior pass after pass and not under local variation. For this reason, the coefficients of the controller cannot compensate for such a sudden and local variation, but are instead oriented toward the achievement of almost steady state conditions. However, the local variation of thermal emission and deposited material reduces pass after pass, highlighting a self-compensating effect during the deposition.