URBAN AND ARCHITECTURAL DESIGN | VIRTUAL PROTOTYPES AND REAL PRODUCTS | WATER ENGINEERING | AEROSPACE ENGINEERING | ARCHITECTURAL COMPOSITION | ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE | BIOENGINEERING | BUILDING ENGINEERING | DESIGN AND TECHNOLOGIES FOR CULTURAL HERITAGES | ELECTRICAL ENGINEERING | ENERGY | GEOMATICS AND INFRASTRUCTURES | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INDUSTRIAL DESIGN AND MULTIMEDIA COMMUNICATION | INFORMATION TECHNOLOGY | INTERIOR DESIGN | MANAGEMENT, ECONOMICS AND INDUSTRIAL ENGINEERING | MANUFACTURING AND PRODUCTION SYSTEMS | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING | **MECHANICAL SYSTEMS ENGINEERING** | PHYSICS | PRESERVATION OF ARCHITECTURAL HERITAGE | PROGRAMMING, MAINTENANCE, REHABILITATION OF THE BUILDING AND URBAN SYSTEMS | RADIATION SCIENCE AND TECHNOLOGY | ROTARY WING AIRCRAFT | SANITARY - ENVIRONMENTAL ENGINEERING | STRUCTURAL SEISMIC AND GEOTECHNICAL ENGINEERING | TECHNOLOGY AND DESIGN FOR ENVIRONMENTAL QUALITY IN BUILDINGS AND URBAN CONTEXT | TERRITORIAL DESIGN AND GOVERNEMENT |

PhD Yearbook | 2010

DOCTORAL PROGRAM IN MECHANICAL SYSTEMS ENGINEERING

Chair:
Prof. Gianpiero Mastinu

The Programme covers many different disciplines and it is particularly devoted to innovation. Both theoretical and experimental activities are undertaken referring to complex mechanical systems. Main topics: Dynamics and vibration of mechanical systems, Machine design, Measurements and experimental techniques, Materials, Methods and tools for industrial design, Ground vehicles.
The faculty is composed by Professors of the Politecnico di Milano (Technical University of Milan) coming from the Department of Mechanical Engineering. The University of Pavia is represented in the faculty.
Experimental research activities are performed in the laboratories of the Department of Mechanical Engineering, in the Laboratory for Robotics, in the Laboratory for the Safety of Transport, and in the Wind Tunnel of the Politecnico di Milano.
At the end of the Programme the PhD candidate will have attended Seminars, High-level Courses, International Congresses, additionally he/she is expected to be able to manage original research activities leading directly to actual results.

Phd in Mechanical Systems Engineering

The PhD Programme aims to serve industrial needs in the field of research and development of Mechanical Systems. PhDs will be specialists ready to react efficiently to the requests of the industry. Innovation and related industrial applications can be boosted by funding doctoral studies.
A list of the last PhD theses (2010) is reported to give an idea of the broad research fields of the Programme in Mechanical Systems Engineering:

- Modeling in the time domain of non linear aerodynamic forces on bride decks
- Dynamics of vertical axis tidal current turbines with freely hinged blades: numerical and experimental analysis
- The truck mounted concrete boom pump system: an active control applied to reduce the boom vibration
- Advances in optimal design of mechanical systems with application to the road vehicles active safety.
- Evaluation of methods for pressure distribution measurement.
- Theoretical and experimental assessment of active safety and comfort of road vehicles.
- Influence of profile modifications on transmission error and noise of spur gears.
- Mechanical design of a FTIR for Mars.
- Innovative prototipal realisation of a plug-in hybrid electrical vehicle: energy control strategies for improving overall efficiency
- Fem approach to spur and helical gears: effects of micro geometries and misalignements on gear mesh characteristics.
- Multiaxial fatigue in the presence of defects.

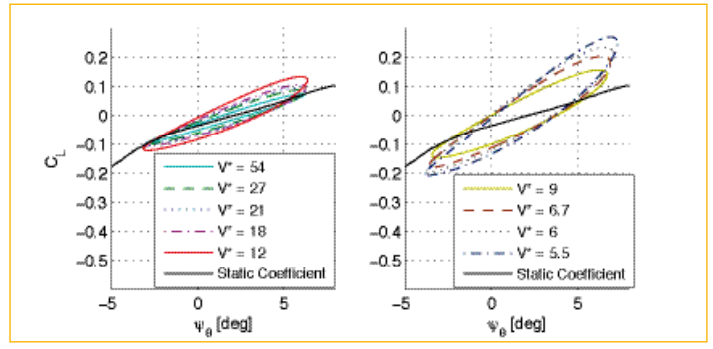
Keywords
Machine dynamics, Mechatronics, Vibration, Structural Reliability, Mechanics of Materials, Composite Materials, Structures, Complex System Optimisation, Ground Vehicles, Industrial Design, Experimental Techniques, Metallurgy, Siderurgy.

MODELING IN THE TIME DOMAIN OF NONLINEAR AERODYNAMIC FORCES ON BRIDE DECKS

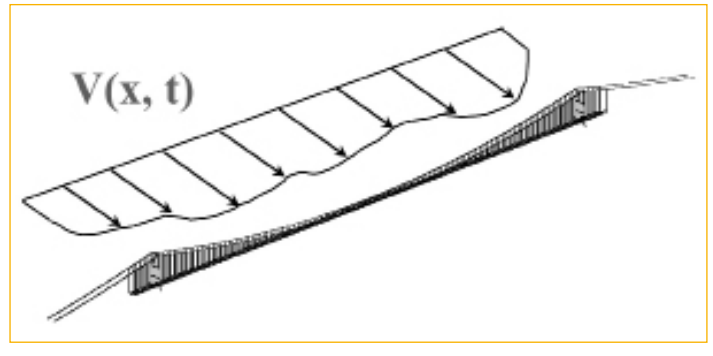
Tommaso Argentini

1. Experimental setup in the wind tunnel

The research has allowed innovative modeling of nonlinear effects of the aerodynamic forces acting on bridge decks. This aspect is very critical, since deck sections with attractive aerodynamic performances required for the feasibility of long span bridges, tend to exhibit non-linear aerodynamics, whose effects on dynamic response of the structure are not yet entirely clear. The objective of the research was therefore to define a methodology for aerodynamic design of bridges, able to take into account non-linearity and to provide analytical-experimental tools to the aerodynamic designer.
In particular, the work of doctoral thesis is dedicated to the study of nonlinear effects related to wide fluctuations of the angle of attack. These large fluctuations can be generated by the combined movement of the structure and variation of large-scale turbulent wind speed components (low frequency).
The study was carried out with two experimental campaigns in the wind tunnel, followed by an analytical and numerical activity (see Fig.1).
The research was initially directed to the design and to the realization of wind tunnel tests on scaled sectional models with deck sections able to exhibit a nonlinear aerodynamic behavior due to large fluctuations of the angle of attack. As a result, using the extensive experimental database, an analytical approach was developed to study the nonlinear phenomena, taking into account the combined effects of turbulence and motion of the deck.
This approach, which introduces the aerodynamic hysteresis loop as a function of the angle of attack, has allowed the development of a nonlinear numerical model in the time domain, for the simulation of the aerodynamic forces (see Fig. 2). The model has been validated through the comparison of experimental results on suspended sectional model, analyzing two different types of deck sections (Adige and Messina). Such a model was used to study a series of nonlinear aeroelastic phenomena, in particular to evaluate the effects of wind turbulence on the dynamic response and on the onset instability.
Finally, a numerical evaluation of the effect of turbulence on instability threshold of a long span suspension bridge was conducted, exciting the structure with a multivariate and multidimensional turbulence (see Fig.3). It is shown that high levels of turbulence can anticipate the threshold instability. In summary, the work has established an experimental methodology to highlight the aerodynamic nonlinearities; it defines an analytical approach to analyze and model them, and it proposes a nonlinear numerical model in the domain in time for the aerodynamic forces, with related strategy for parameter identification and validation, allowing an assessment of the effects of turbulence on stability.
In conclusion, the research has provided the bases of a methodology for aerodynamic design of bridges, including nonlinearity analysis, providing the analytical and experimental tools to the designer for the correct evaluation of the aeroelastic problem.



2. Example of aerodynamic lift hysteresis loops at different reduced velocities

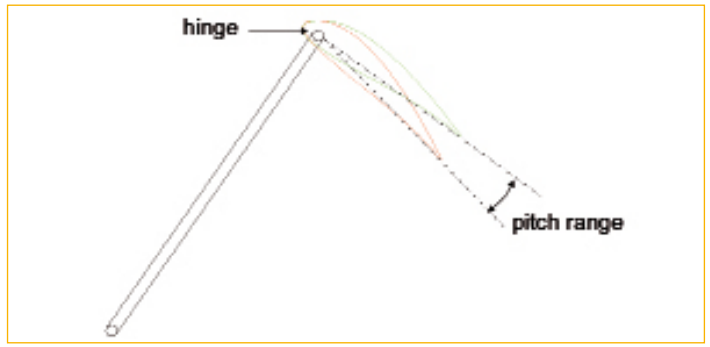


3. Sketch of a full bridge model excited by multivariate-multidimensional wind field

DYNAMICS OF VERTICAL AXIS TIDAL CURRENT TURBINES WITH FREELY HINGED BLADES: NUMERICAL AND EXPERIMENTAL ANALYSIS

Giancarlo Galli

This PhD thesis deals with the power generation from renewable resources.
This topic is very actual since currently the global electrical energy demand, that is continuously increasing, is mainly satisfied by the combustion of fossil fuels which are responsible of pollution and climate changes.
Nowadays the national governments and the international scientific community are mainly focusing their attention on wind energy. Unfortunately this renewable resource represents an integration but not an alternative to fossil fuels because of its unpredictability which can't assure the fulfilment of the average energy demand.
The hydraulic energy represents an optimal solution to guarantee the generation of a reliable quantity of power since the water dynamics is characterized by some natural phenomena that are deterministic, like tides. Tides are completely predictable because they depend exclusively on the lunar cycles. In fact the gravitational attraction of the moon causes a gradient of the level of the earth's water surfaces with a connected water flow that represents the tidal current.
In order to understand the potentiality of tides, it is enough to know that the theoretically extractable power in Europe is about 75 GW, equal to the demand of 25 millions consumers.
It becomes necessary to chose the most proper type of turbine to exploit this energy resource. Since tidal currents speed is characterized by a continuously changing direction, vertical axis turbines are the most suitable solution because, unlike horizontal axis turbines, their performances are not affected by the direction of the incoming flow.
The research activity developed in this thesis aims at the analysis of the dynamics of a vertical axis turbine in order to understand which design choices can increase its efficiency. In particular the effect of a passive device, constituted by freely hinged blades between two bumpstops (figure 1), has been deeply investigated.



1. scheme of the passive device with a freely hinged blade between two bumpstops

The first stage of the research activity has concerned the study of the fluid dynamics of a vertical axis turbine in order to comprehend the functioning of the passive device. Therefore a simplified bidimensional model has been developed considering a single fixed blade and neglecting the wake effects. The results of the simulations have been processed to create a map of the average power produced by the turbine in function of the rotor's rotational speed and of the blade's pitch angle. This map has been used to set the optimal values of the bumpstops limits. Moreover, analysing the results for the optimal rotational speed, it has been verified that the passive device produces a considerable increase of the turbine's performances. In spite of the strong adopted simplifications, the results obtained with this simplified model are considered very important because the passive device acts inside a zone where the wake effects are negligible.
The subsequent stage has concerned the choice of the most suitable numerical model to implement the dynamic behaviour of the free blade.
It has been therefore decided to compare the performances of two existing methods, the Double Multiple Streamtube and the Computational Fluid Dynamics, that have been developed to model the wake effects for the fixed blade case.
The comparison of the obtained results has determined the choice of the Double Multiple Streamtube method for its good accuracy with limited computational time in evaluating the turbine's performance.
Once the numerical method has been chosen, all the necessary modifications to model the behaviour of the freely hinged blade have been implemented.
In particular a new numerical method, called Dynamic Double Multiple Streamtube, has been created mixing the flow perturbations calculated by the Double Multiple Streamtube and the dynamic equilibrium of the blade. The new method consists of the following iterative algorithm:

1. guess of the initial pitch of the blade;
2. calculation of the flow perturbation with the Double Multiple Streamtube;
3. evaluation of fluid dynamic forces;
4. calculation of the effective pitch of the blade from the dynamic equilibrium using an Euler implicit solver;
5. comparison of the effective pitch with the bumpstops limits;
6. if the pitch value doesn't converge, the algorithm restarts from step 2.

Finally the new numerical method has been validated with experimental tests. Since the marine environment does not allow to realize complex measurements, an experimental campaign has been performed in the wind tunnel on a scale model. The tests have been designed using the Riabucinski-Buckingham theorem and imposing the similarity between the prototype and the model in terms of adimensional variables. However it has not been possible to realize a perfect similarity because of the constraints due to the dimensions of the test chamber and the forced choice of the fluid. For this reason a second experimental campaign has been performed directly on the prototype in the Straits of Messina.
The results of the developed numerical method have shown a good agreement with the measurements of both experimental campaigns.

2. Experimental tests on the model in the wind tunnel

3. Experimental tests on the prototype in the Straits of Messina

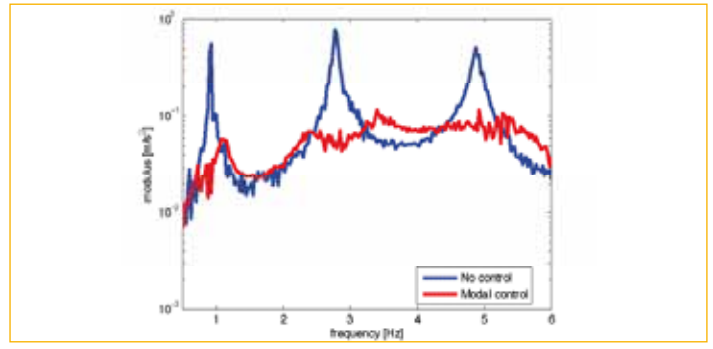
THE TRUCK MOUNTED CONCRETE BOOM PUMP SYSTEM: AN ACTIVE CONTROL APPLIED TO REDUCE THE BOOM VIBRATIONS

Christian Ghielmetti

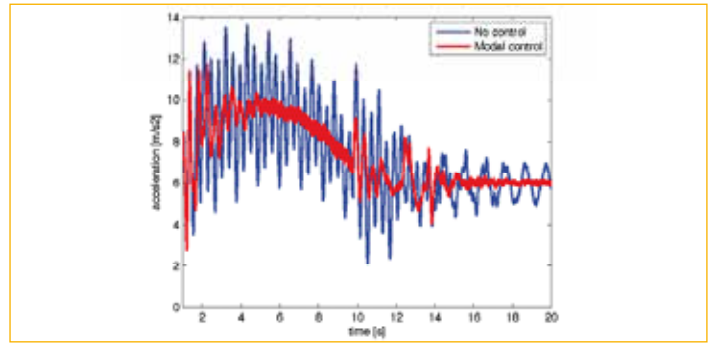
During the last years the construction machinery area had a great development in size increasing and lightening. Considering for example the concrete displacing booms, this trend is well visible.
The requirement of weight reduction, in order to improve the system performances, leads to structures characterized by high flexibility and low damping. These characteristics, associated to the dynamics loads due to the large motion of the structure and the concrete flow, involve a high mechanical stress of the material. These structures suffer from a fatigue and instability issues involving, as a consequence, several matter about the safety. In order to reduce crack propagation and increase the booms lifetime it's necessary to decrease the stress by suppressing vibrations of the entire system. Traditional external passive control methods are generally more invasive, introducing mass on the structure, and less effective in a large range of frequency. On the other hand, the active control is an attractive solution, especially considering the wide development of calculator hardware and the consequent cost reduction. Moreover this type of control allows to introduce the energy in the system by using the same actuators in charge of the boom motion, without placing new ones. In literature several examples of controlled flexible structures can be found. For example Balas (1978) and Meirovitch (1984) studied vibration suppression applying the modal expansion theorem and the modal control. In the following years other studies (Wang, 2002) allowed to define an algorithm able to efficiently respond to a disturbance force at a frequency far from the system natural ones. The aim of the present work is the definition of a control laws in order to suppress vibrations resulting from both large motion of the boom's arms and concrete pumping, due to the alternative pumping group work. The reference numerical model, required for the control law synthesis and the numerical simulations, is created adopting the multibody (MB) and FEM techniques for the boom and with a proportional integrative derivative (PID) control for the pumping group. With these models was possible to advance in a continuous numerical/experimental comparison of different solutions and hypotheses. With regard to the boom was developed, in MATLAB® environment, a nonlinear dynamic model able to describe the combined effect of large motion and elastic vibrations of the structure, as well as evaluating the natural frequencies of the boom and manage the application of modal and feed-forward control. Control logics, for the boom, were developed using modern control techniques (pole-placement) together with the assistance of a modal observer for the reconstruction of the state of the system. The vibration control logic adopted is based on an independent modal approach (Meirovitch, 1983). Following this approach the control action is calculated starting from the system vibratory state and an opportunely defined gain matrix. In particular the vibratory state is described by a set of modal coordinates representing the system dynamics in the frequency range of interest. The modal coordinates, that for a generic application cannot be measured directly (unless to use distributed sensors

1. The full-scale prototype truck

(Lee,1990)), were estimated by a modal observer, designed in order to avoid the spillover effect problems. As for the boom, even for the pumping group unit and for the hydraulic actuators, were developed non-linear numerical models in MATLAB® environment. These models were used both in the process of identification of some coefficients and of the main critical factors present in the current constructive solutions, both in the prediction of modifications on these systems. In addition to the numerical modeling, were carried out many experimental tests on a small scale or on real scale test rigs. In the period of theses, from January 2007 to December 2009, were done the implementation and management of five experimental test rigs including three of them devoted to the boom and two dedicated to the pumping group unit and to the hydraulic actuator. First of all, the boom control logics were tested on a laboratory test rig, expressly design for this research activity. It consists of a scale model with elastic characteristics similar to those of the real booms. This prototype was designed to investigate the flexibility problems related to the commercial boom and in order to develop and validate the proposal control logic method. Later, the control logic tested on the laboratory test rig, were applied and tested first on a real boom linked on the ground an than on the full-scale prototype truck of the company, called K41L. These latest tests were done both in test area and in the construction area. The hydraulic actuators test rig, preparatory to the physical parameters knowledge of the forces on the boom, showed the behavior of the hydraulic cylinders under particular working conditions and, in the detailed, were used to derive the transfer functions to use in the program dedicated to the boom. The pumping group numerical/experimental comparisons were possible through the implementation of a dedicated test rig with which, through a series of measures and data analysis, it was possible to completely understand the behavior of the system, its problems and the kind of forces given to the boom. With this thesis work have been earned several aims and in particular the realization of the numerical models of the boom, hydraulic cylinder and pumping group and the practical application of the control logic system on the full-scale truck mounted concrete boom pump. The design and the improvement of the modal control logic, together with the development of diagnostic applications, are still now under improvement and are part of the future research projects of the machines for distribution of concrete.



2. The modal control application



3. The decreasing vibrations

ADVANCES IN OPTIMAL DESIGN OF MECHANICAL SYSTEMS WITH APPLICATION TO THE ROAD VEHICLES ACTIVE SAFETY

Paolo Guarneri

The objective of this research work is the study of optimization methods with focus on the capability to solve efficiently mechanical engineering design problems. The optimization approach allows the designer to solve efficiently complex design problems that cannot be easily handled due to the large number of design criteria and constraints.
The study of the optimization techniques is performed along with the application to some practical problems, the design a new brake caliper and the tuning of road vehicles suspension systems.
In the field of the vehicle design the problems are multi-objective as different performance such as the safety, the handling and the comfort have to be considered. To solve such multi-objective problems, the parameter space investigation method (PSI) can be conveniently used. The method consists into the sampling of the high dimensional design domain to perform the optimal choice of the solutions. Given the high level of detail and accuracy required, the mechanical models are often computationally demanding. To take into account both the accuracy and the computational efficiency, an analysis based on the dispersion estimation of the sampling sequence is proposed.

Due to the improving in the computational speed, the complexity of the models used in the design stage is increasing. A decomposition based approach is attractive for solving large scale problems. The idea is to decompose the problem into smaller and simpler sub-problems. The Analytical Target Cascading (ATC) formulation has been studied and properly modified to improve the computational efficiency without reducing the accuracy. The modified algorithm can be applied to a class of problems solve with a significant reduction in the computational effort. This class of problems that has been identified includes interesting engineering problems as the structural optimization and multidisciplinary aircrafts design.

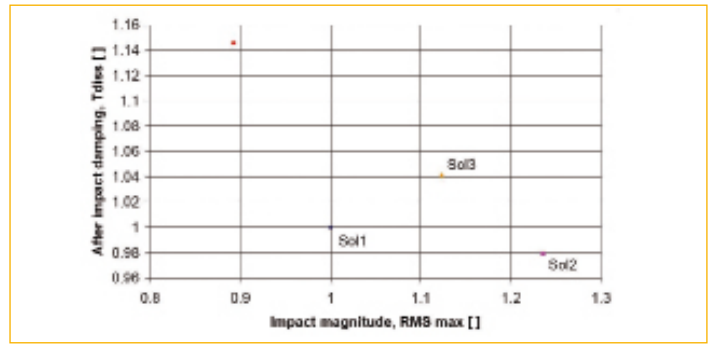
Optimal design of a new brake caliper

The PSI method has been applied to design a new brake caliper which is suitable for electric actuation. Such a brake caliper allows an improvement to the vehicle safety and controllability and it is ideal for the integration in the hybrid or full electric vehicles. The main issue is related to the layout constraints and the high energy required to generate the usual braking forces. The problem has been addresses by means of the efficiency of the brake caliper in order to define a proper solution which is able to generate the braking torque while requiring lower actuation forces than the conventional hydraulic brake calipers.
Despite the complexity of the problem, the optimization approach lead to the manufacturing of a caliper prototype. A patent is pending on the new brake caliper. The experimental tests (see figure 1) showed that the new caliper actually needs smaller actuation forces to generate braking torques.

Optimal tuning of road vehicle suspension systems

The optimization theory can be applied to define the optimal setting of road vehicles suspension systems.
To perform the optimization, a mathematical model relating the design variables and the objective functions is necessary. In the case of the assessment of the vibration and harshness performance, the mathematical models required are too complex due to the non linearities of the tire, elastic bushings and damper. The experimental measurement is the therefore the most effective way to characterize the VH behavior of different design solutions.
A method has been developed to obtain performance indexes which are able to summarize the VH performance by the measure of the loads acting the at interfaces between the suspension system and the car chassis. The measures are performed on an indoor test facility while the tire is passing over an obstacle (cleat). This way, the impact magnitude and the after impact damping, which represent the most important features for VH purposes, are properly measured. To fully characterize the VH behavior, test on flat surface are considered as well to determine the effect of the tire unevenness and wheel unbalance. As in the case of mathematical modeling, the key point is the accuracy of the proposed method. The test rig has different mechanical characteristics with respect to the car chassis and an analysis based on the coupling between the test rig structure and the suspension system is carried out to show that the loads measured on the test rig are reliable prediction of the actual ones. The different design solutions tested have been compared by means of the experimentally derived indexes. To take into account the tradeoff between all the indexes (i.e. objective functions) the k-optimality criteria has been successfully applied to compare all the solutions. In figure 2 the tradeoff between the impact magnitude and the damping is shown for the different design solutions tested (the values are scaled with respect the "Sol1" ones).

1. The brake caliper prototype under testing



2. Tradeoff between the impact magnitude and the after impact damping

EVALUATION OF METHODS FOR PRESSURE DISTRIBUTION MEASUREMENT

Gerardo Lanfranchi

The objective of the present work is to evaluate different methods to measure the contact pressure distribution.
The pressure distribution taken into consideration in this work regards the medical application field; the information obtained may be used by the medical staff and by the health workers operating in the rehabilitation and orthopaedic sectors in order to develop and realize medical devices such as prosthesis, orthesis and braces. Said devices support the diagnosis and the therapies for those pathologies linked to an improper pressure contact distribution. The work has been divided into two parts; the first one analyzes the current technologies present on the market, while in the second one a new method for the contact pressure measurement has been proposed using thermo-graphic images
The analysis of the sensors present on the market has led to the calibration of sensors linking the pressure distribution to a variation in the electric resistance of the used material (typical feature of the Nitta Corporation sensors) and of sensors linking the pressure variation to an electric capacity difference among two surfaces that constitute the sensor and that work as condenser (Novel sensors). During said analysis, the sensor characterization, both dynamic and static, has been realized. It has been necessary to develop and realize measurement devices and methods able to determine the static and dynamic response of the sensors subjected to controller inputs under calibration and real conditions. The need to read the signals and to control the systems has led to the implementation of an analysis software appropriate to this task. The analysis of the signal, of the transfer function and of the sensor behaviour in different environmental and usage conditions has permitted to obtain an indication on the quality and the limits of the analysed measurement instruments.
The sensor metrological limits have been evaluated and a lack of adaptability in situations where the evaluation of the pressure distribution is necessary (such as the orthesis-limb interface) has been observed. Moreover, the fundamental need was to obtain a versatile instrument with low management costs, without drift problems in time and temperatures and easy to be used: it has therefore been identified a potentially apt method based on a measurement systems without contact. After an analysis of the thermal system realized throughout the orthesis-limb coupling, a potential no-contact method seems to be practicable analyzing the orthesis temperature distribution. This method would be valuable for the determination of the pressure distribution in order to identify and localize the over-pressure zones. The limb transfers heat to the structure (made of Orfit plastic material) allowing to evaluate its superficial temperature from the outside thanks to a thermo-camera; the thermo-camera reading depends on the efficiency of the heat transfer that is proportional to the pressure for "inert material surfaces". The applicability of this concept to the contact involving a human derma is not at all obvious.
Therefore, it has been developed a thermal model of the hand-orthesis system, to identify the fundamental parameters and to characterize them. The thermal model allowed to underline, further than the not influencing parameters, the connection between the contact pressure and the temperature divergence on the orthesis surface. However, the validity of the method is based on the hypothesis that the thermal skin resistance, one of the system parameters, decrease when the contact pressure rises. The skin thermal resistance has achieved much interest in literature moreover the relationship with the pressure has not been investigated at all. In order to characterize the skin thermal resistance, a measurement system has been designed and developed: this system generates a controlled heat flux and measures the relative temperature difference, thus allowing to obtain the parameter of interest. In order to determine the factors affecting this parameter, several tests have been implemented with the two-level factorial plan technique and the results have been analyzed with ANOVA techniques. The analysis allowed to establish that the thermal resistance is influenced not only by the contact pressure, but also by the blood pressure of the interested area and this is a characteristic proper of the single analyzed subject. However, the value, once characterized on the specific subject, allows to connect pressure and temperature at least for pressure levels that do not interfere with the blood flow.
In order to infer the pressure from the thermo-graphic image, an analysis software has been implemented to draw the values of the space gradient and then the divergence. The implemented system allows to acquire the thermo-camera images and to analyze them in a following phase. Processing the information on the temperature distribution, it is possible to focus the analysis on one or more specific zones; it is then possible to have a single thermal acquisition to analyze more zones of interest afterwards. The realized measurements present a standard deviation of 2% and all comparisons an verification carried out have provided encouraging, though not definite, results.
In order to validate the no-contact measurement system from a metrological point of view, it would be necessary to verify the system with respect to conventional techniques having accuracy better than that of the proposed system. Three methods of comparison have been evaluated: the Novel capacitive system, a measurement system based on the use of load cells and the Fujifilm measurement system. All of them present substantial limits in this kind of application. The use of the available Novel sensors does not allow an accurate comparison due to its low space resolution and it determine a high uncertainty since the maximum pressures are close to the minimum measurable level. For what concerns the use of the load cells, it has been observed a good correspondence (within 5 pixels of the image) between the centre of the pressure distributions and the position of the pressure centre provided by the load cells. However, the limit of this comparison is that it only provides a global judgement and it does not allow a precise check of the pressure; it is therefore true that the positive results obtained on a series of different images provide a low possibility that the systematically correct centres correspond to wrong distributions. For what concerns the last method, the Fujifilm, the consideration may only be qualitative about the pressure trend and also in this case the resolution is too low to allow for a significant comparison. Therefore, the conclusion is that all the conventional measurement methods used for the comparison have provided an indication of compatibility with the proposed one, but they cannot represent calibration references with sufficiently reduced uncertainties and further work is needed to validate what is still only a promising candidate method.

THEORETICAL AND EXPERIMENTAL ASSESSMENT OF ACTIVE SAFETY AND COMFORT OF ROAD VEHICLES

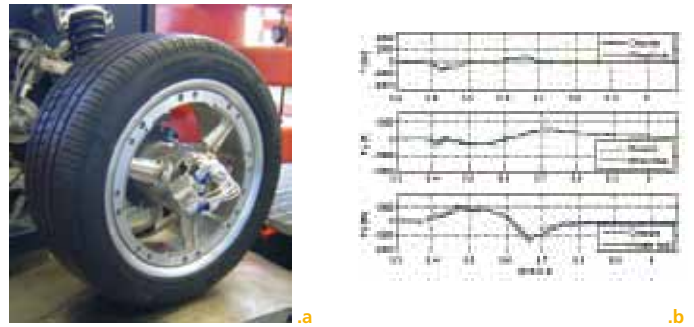
Gianpiero Rocca

The research project: aims

The constant need for faster ways of transportation has lead to a great deal of advancements, particularly in the area of personal mobility. However, this increasing necessity has also lead to different problems, especially regarding the safety of the passengers. The vision of accident-free traffic is one of the most challenging in today's and future automotive market. The improvement of traffic or driving safety can only be achieved by an optimised integration of different vehicle systems such as driver information systems, power train management, chassis systems and external services. The real time measure of the forces exchanged between tire and road is crucial for analysing and monitoring the dynamic behavior of a vehicle. The development of a new smart wheel for passenger cars and light commercial vehicles is the main objective of this PhD thesis and it is described in the first part of the work. The smart wheel is a sensor able to measure the three forces and moments acting at the wheel hub. The wheel is based on an original structural concept and it appears to be rather simple to be implemented in future automobiles. The simple design, the high performances (accuracy, natural frequency, limited mass, etc.) and the low cost represent the main features of the sensor. The performances of the smart wheel fit well the needs of improving the active safety of automobiles. The information given by the wheel should lead to considerable improvement of the ABS and ESP/VDC performance with respect to today control logics.
The real time measure of the driving forces acting on the tires is extremely important not only for improving the dynamic behavior of road vehicles but yet during the design step of a full vehicle and its subsystems, i.e. suspension and brake systems, chassis, etc. Theoretical and experimental methods for the NVH analysis of automotive brake and suspension systems are described in the second part of this PhD thesis. The experimental activities have been performed on a rotating drum located in the Laboratory for the Safety of Transport at Politecnico di Milano.

The smart wheel concept design

The structural part of the smart wheel is composed basically by three spokes and particular joints, which do realize the physical link between the three spoke structure (wheel hub) and the wheel rim.
Analytical and finite element models have been implemented in order to prevent the sensor behavior during the designing stage. The smart wheel has to be designed in order to have weight and stiffness properties similar to those of the standards wheels but, at the same time, high forces/moments sensitivity and low cross-talk values have to be guarantee.
Multi-Objective Programming has been used to optimize the system performances. The optimal values of the smart wheel parameters (stiffness of the three spoke structure, geometry of each spoke, strain gauges positions..) have been computed and the joint structure has been defined by using topology optimization techniques. In order to adapt the smart wheel to a common passenger car, the whole sensor has been finally verified under radial and cornering loads according to TUV tests criteria.
The measurement of the three spoke deformations is obtained by means of 12 strain gauges. The six half-bridges signals are linearly correlated to the forces and moments acting at the wheel hub. As the measuring hub rotates, a telemetry system has been designed and developed with the technical support of ST MicroElectronics to transmit the six voltage signals from the strain gauges to the vehicle body. The system requires low power with a constant voltage.
After an accurate calibration phase, a dynamic analysis of the sensor performances has been completed thought indoor tests [Fig. 1]. The forces measured at the wheel hub have been compared to those applied at the suspension-chassis interface as the wheel passes over a cleat at different vehicle speeds.
Then the smart wheel has been fitted to a production passenger car. The force and moment signals have been acquired both during cleat tests and braking manoeuvres. The high reliability of the whole measuring system has been verified satisfactorily.



**1. Smart wheel/suspension system (.a).
In (.b) the resultant forces at the suspension-chassis interface are compared to those measured by the smart wheel**

A method for VH analysis of automotive suspension system

The vibration of the vehicle chassis depends mainly on the tire, on the suspension geometry, on the stiffnesses of the springs and of the bushings, on the damper setting, on the suspension structural features and on the geometric tolerances of the suspension components. Due to these many factors influencing the chassis vibrations and harshness (VH), it is rather difficult to model the suspension vibration behavior. Experimental activities are necessary to obtain a reliable estimation of the loads acting at suspension/chassis joining points for comfort and durability purposes.
A method and test facility has been developed in order to characterize the VH performances of a suspension system up to 120 Hz and to perform a relatively quick and efficient suspension tuning. Two different kinds of tests can be performed. In the first kind, the tire/wheel unbalance effect on the suspension system behavior is analyzed by testing the suspension system from zero to the vehicle maximum speed on a flat surface and by monitoring the forces transmitted to the chassis, in particular the harmonic components at 1x and 2x the rotational speed of the wheel. In the second kind of tests, the suspension system is excited as the wheel passed over different cleats fixed on the drum. By analyzing the forces and the acceleration (such as the wheel centre displacements) measured on the suspension system, a set of performance indices has been derived both in time and frequency domain. The experimental data obtained from the indoor testing are very useful for the development of accurate physical and numerical models of a vehicle suspension system and, consequently, for improving the suspension dynamic behavior (optimization process).

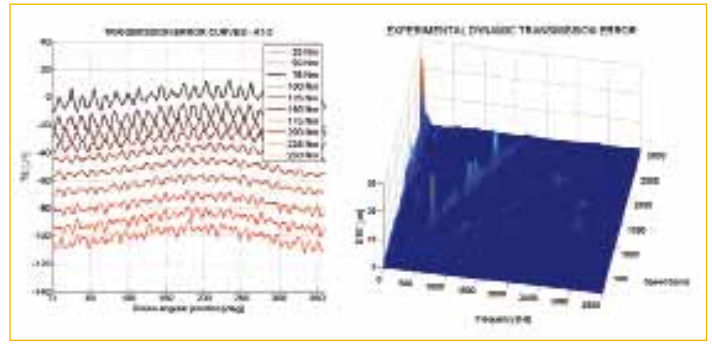
INFLUENCE OF PROFILE MODIFICATIONS ON TRANSMISSION ERROR AND NOISE OF SPUR GEARS

Fabrizio Rossi

Gear transmission error is defined as the difference between the actual position of the driven gear and its theoretical one in case of prefect transmission. The main causes of transmission error are the deformation of the meshing teeth under the applied load, as well as the manufacturing and assembling errors. In quasi-static conditions, transmission error is called *static transmission error* and it can be thought of as a little vibration, originating at the gear mesh, pushing the driven gear backwards and forwards. This little imposed displacement, responsible of impacts at the beginning of the gear mesh and vibrations of the gear blanks, is unanimously considered as a powerful indicator of gears vibrations and noise. The vibrations originating at the gear mesh can be amplified by the dynamics of the gear transmission and they can turn into a bigger vibration called *dynamic transmission error*; then, this vibration can propagate through shafts and supports, reaching the gearbox walls that radiate them outwards as loudspeakers, producing noise. The gear designer can reduce transmission error both statically, with opportune profile modifications, and dynamically, by means of an accurate study of the dynamics of the gear transmission. Nevertheless, the validation of any theoretical model, available since design phase, requires experimental tests.

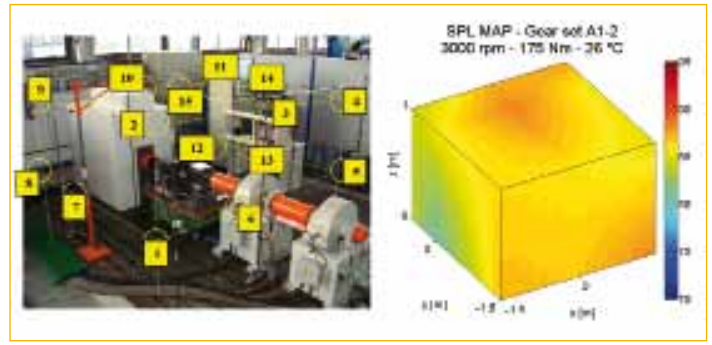
1. Test rig for the measurement of transmission error and noise of parallel axis gear sets

In this study, the influence of profile modifications on noise and transmission error of spur gears is investigated. A test facility is setup in order to measure both transmission error and noise of parallel axis gear sets. The setup of the test rig includes the development of a gear casing for the lubrication of the gear sets and for an easy and quick mounting and dismounting of the gears to be tested; the same gear casing is designed according to the encoders tolerances prescribed in the data sheet, in order to guarantee the measurement accuracy specified by the manufacturer. At the same time, a measurement system is designed to measure both static and dynamic transmission error using optical encoders; the measurement system is based on an innovative data acquisition and elaboration procedure, representing an alternative to the common phase difference techniques employed in traditional transmission error measurements. By means of this procedure, sampled data are reconstructed by interpolation and, using the once-per-revolution signals of the two encoders, all TE measurements can be made from a common pair of teeth in contact.
Next, a model for the prediction of static transmission error is developed, considering the effect of the tooth bending compliance, the Hertzian compliance and the tooth base rotation on gear mesh stiffness. The model calculates static transmission error in function of both the applied torque and the gears geometry; its validation is performed both numerically, comparing its results to those ones obtained using an existing commercial software, and experimentally. To this aim, four gear sets, with the same macro-geometry, but different profile modifications, are considered and static transmission error is measured for different values of input torques on the test facility previously described; experimental results are compared to theoretical ones.



2. (Left) Static transmission error curves. (Right) Dynamic transmission error waterfall diagram

Then, different dynamic models of the test facility are considered, in order to investigate the level of complexity necessary to accurately describe the dynamics of the test rig. Starting from a two degrees of freedom lumped parameters linear model, excited at the gear mesh by an imposed displacement constraint modelling static transmission error, the scheme complexity is increased up to consider a finite elements model of the gear transmission. Couplings between transverse and torsional vibration, due to bearings and shafts compliances, are investigated, while the validation of the models is performed measuring dynamic transmission error up to 3000 rpm.
Finally, the influence of profile modifications on gear noise is investigated. The sound pressure of the four gear sets is measured for different values of speed and torque. The comparison between experimental and theoretical results proves the close correspondence between measured sound pressure levels and dynamic mesh forces predicted on the basis of static transmission error measurements. More accurate gear noise measurements are presented, showing that the most significant sound emission occurs in correspondence of the gear mesh and that the biggest harmonic amplification is found in correspondence of the vibration mode associated to the highest mesh stiffness excitation.



3. Gear noise measurements

MECHANICAL DESIGN OF A FTIR FOR MARS

Diego Scaccabarozzi

The objective of this work is the design of a Fourier Infrared spectrometer for the ESA mission "ExoMars Pasteur 2013". MIMA, Mars Infrared Mapper, will observe Mars ground and atmosphere searching for traces and present or past life. The design constraints defined for the mission are very strict: an overall mass of 1 kg and a size limited by a volume of 140x140x120 mm3. Furthermore, the instrument has to be designed to overcome a quasi-static acceleration of 1000m/s2, corresponding to the shock expected during the landing on mars ground, and withstand a severe thermal environment, without power for thermal control due to the restricted power budget. Strong vibrations with high acceleration levels are expected in a wide frequency range, resistance and mechanical tolerances fulfilment have to be assured. Calibration and data processing procedures have to be designed in order to provide correct measurements within this harsh scenario.
The mechanical design has been supported by finite element models which provided the instrument behaviour with the expected static and dynamic loading; the thermal environment has been studied and the effect on the instrument evaluated by means of thermo-elastic analyses which computed the thermal stresses and the instrument misalignments. In parallel the calibration procedure has been optimized by means of uncertainty analysis which included the error contribution of the measurement chain and settled the requirements for the reference sources. Due to the limits of the existing approaches, a new data processing procedure for the extraction of the spectrum from the interferogram has been conceived. The new method has been validated by applying it to the mars' measurements of a FTIR onboard the MarsEpress mission (PFS).
The final result of this work is an instrument mockup with fulfilling the requirements in terms of mass and size which has been assembled and successfully tested at the vibration levels defined for the mission. Beside this, some relevant outcomes have to be evidenced: the models correctly predict the behaviour of the system whose validation has been provided by the mock-up test campaign. The thermo-elastic analyses have pointed out the necessity of a partial re-design of the instrument links with the Rover to avoid heavy penalisation of the instrument performances. The calibration sources have been optimised by using a specially designed

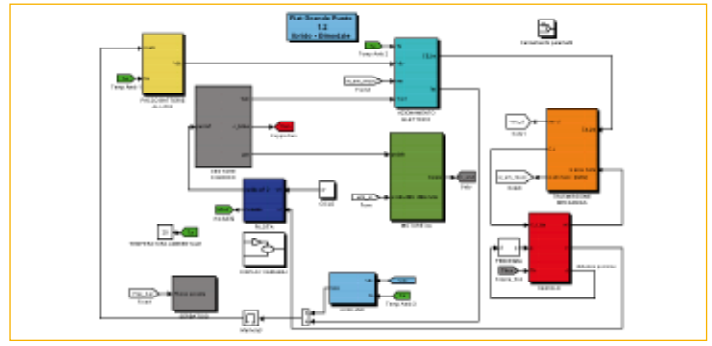
1. MIMA Mars Infrared MApper

cover with a selectively-reflecting coating which was the result of a trade-off between mass, power, size constraints, under the accuracy requirements constraints. Finally, the analyses carried out on PFS data showed that the innovative procedure is capable to detect and retrieve the correct spectrum even in the spectral regions affected by absorption bands, where the classical approaches fail and allows to cope with instrument temperature changes that for MIMA will be dramatic given the mars surface environment.

INNOVATIVE PROTOTYPAL REALIZATION OF A PLUG-IN HYBRID ELECTRICAL VEHICLE: ENERGY CONTROL STRATEGIES FOR IMPROVING OVERALL EFFICIENCY

Davide Tarsitano

Nowadays the greatest part of the efforts to meet fuel economy and to reduce pollutant emissions are directed toward the hybridization of automotive drive trains. In particular the design of hybrid vehicles requires a complete system analysis including the control of the energy given from the on board source, the optimization of the electric and electronic devices installed on the vehicle and the design of all the mechanical connection between the different power sources to reach required performances. The aim of the thesis is to develop a Plug-In Hybrid Electrical Vehicle (PHEV) adding an hybridization kit to a conventional vehicle produced in series. Plug-in Hybrid Electrical Vehicle can be very useful to improve fuel economy and reduce the level of pollution especially in the urban area. This kind of vehicle install on board a large battery pack in order to assure a good autonomy distance range in pure electric (zero emission) operating mode.
In order to correctly design the components of the electrical drive train a numerical simulation model has been set up. The simulation model has been developed using the object oriented approach: by this the model becomes quickly reconfigurable for analyze different performances due to different drive train architecture or due to a new component of the drive train.
In the model each component of the drive train has been consdidered: driver, vehicle control system, Li-ion battery, inverter and electric motor, gear box, clutch, ICE motor, fuel tank, auxiliary on board electrical loads and a longitudinal dynamic of the vehicle. The objects set represents the whole vehicle model. The model has been developed using Matlab/ Simulink simulation tool and in Fig. 1 it is shown the main parts of this model.
The numerical simulation model has so been used in order to correctly size the performances of the electrical drive train. The components have been installed into the vehicle which is shown in Fig. 2.
This vehicle has been instrumented with a large number of transducers in order to have a wide analysis of vehicle's performances under different conditions (for example urban or suburban driving, enable or disable regenerative braking).
Using the experimental data collected during the tests it has finally been possible to refine the model by specific test for parameter identification and then it has been possible to validate the simulation model. For this aim simulation results have been compared with the experimental ones obtained on the prototype where the same drive cycle has been adopted.
At last the numerical simulation model has been used in order to analyze the benefits achievable using the Plug-In HEV as a conventional hybrid one, in other words using both the thermal engine and the electrical motor on the same drive cycle. Different control strategies have been taken into account.



1. The numerical simulation model for the prototypal vehicle

2. The prototypal vehicle

3. The prototypal at Monza race for FIA Alternative Energy Cup

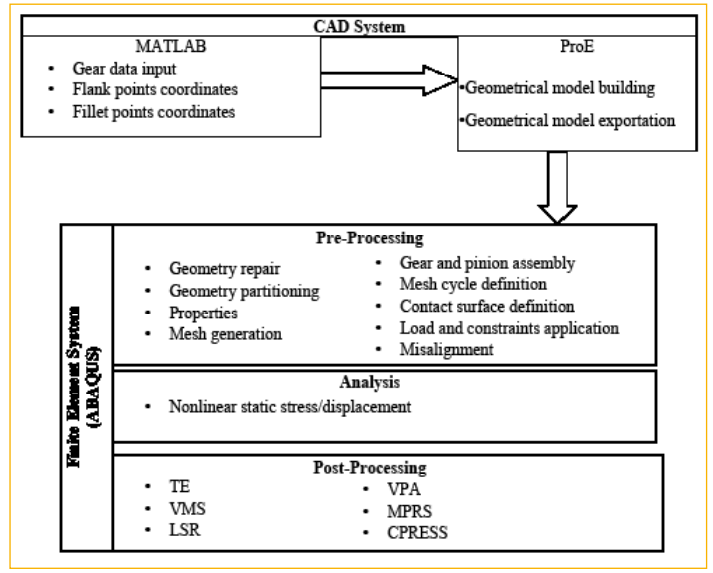
The most promising result has been obtained, in the simulations performed, using a Start&Stop strategy with static thresholds: in other words under a certain speed threshold the vehicle is propelled by the electrical motor and over this threshold the vehicle is propelled by the thermal engine. An hysteresis band is introduced in order to avoid rapid changes of drive mode.

The Start&Stop control strategy has finally been downloaded into the prototypal car control board. The behavior of the real vehicle is very similar to that obtained with the numerical simulation model, confirming that the model, described into the thesis, is a good anticipatory instrument to evaluate vehicle performances considering different drive train configuration, different devices and different control strategies. At last the prototypal vehicle, with the Start&Stop strategy, has run the Monza race of the FIA Alternative Energy Cup (Fig. 3), winning the award for the vehicle whit the lower value of hydrocarbon emissions.

FEM APPROACH TO SPUR AND HELICAL GEARS: EFFECTS OF MICRO GEOMETRIES AND MISALIGNMENTS ON GEAR MESH CHARACTERISTICS

Yonatan Afework Tesfahunegn

Gear drive systems are still the most common mechanical element used to transfer power, adjust rotational speeds or change its directions. Gears can be designed to fulfill many of the possible axial position, power requirements, speed or transfer ratio. However the design is highly complicated art. Gears are reliable, very efficient and, considering what they deliver, very compact. The constant pressure to build less expensive, quieter running, reduce size, increase the service life, minimize the noise emissions and improve the transmission accuracy of power drive trains has resulted in a steady change in gear designs. Today's basic design requirements of gear transmissions are not only resistance and reliability, but also good efficiency, low vibration and noise emissions under normal conditions taking into account the adverse effects of manufacturing errors and variations as well as elastic deformations of the support structures. Supporting structures, gear macro and micro geometry and textures are some of the major issue in the design of a geared system that fulfils all these requirements. In designing a geared system, a designer has then to consider all these aspects, and to be able to predict how each choice influences gear behavior. In particular, the design of gear flank micro-geometry requires cutting tools that are able to predict their effects on gear meshing in actual operating conditions. Among many other features, these tools have also to cope with non-linear modifications, which are nowadays quite easily feasible as a result of the improvements of the modern gear grinders. The design requirements that have been mentioned so far are difficult to fulfill all simultaneously. A potential solution for one of the requirement might not necessarily be beneficial for the others. Durability requirements may come up after a potential noise reduction solution is implemented and vice versa. If the target is to minimize noise then one of the main tests is transmission error test but this is of no use for assessing strength. Conversely, if the requirement is for maximum strength, especially for low speed gears, then it is essential to carry out a bedding check to make sure that the major part of the face of the gear tooth is working but a bedding check is not a valid predictor of noise. Hence the lack of connection between noise and durability presents difficulties when it comes to



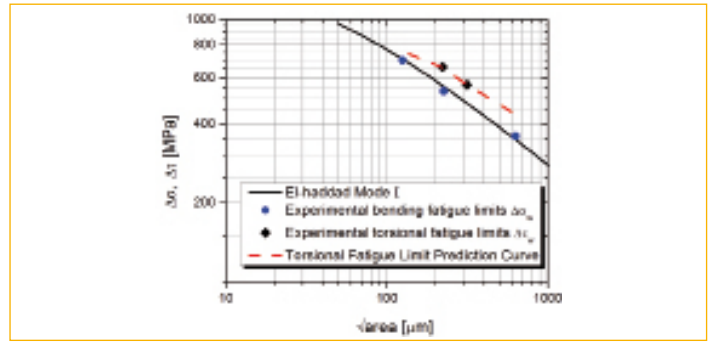
1. Process flow chart

MULTIAXIAL FATIGUE IN THE PRESENCE OF DEFECTS

Khaydar Valiullin

testing the gears on production. This lack of connection between the design requirements motivates this research in order to develop a method that can give simultaneously all the design requirements. The method that is used in this thesis is a numerical approach, i.e. non linear finite element method. In spite of the number of investigations devoted to gear research and analysis a general approach capable of computing stresses and TE simultaneously still remains to be developed.The goals of this research work were to study the effects of micro geometries and misalignments on gear mesh characteristics (GMCs) of spur and helical gears by means of non linear finite element method. Results that are obtained from the course of engagement between pinion and gear in a complete mesh cycle can be defined as Gear Mesh Characteristics (GMCs). The gear mesh characteristics (GMCs) are the following: 1) Transmission Error (TE), 2) Variable Mesh Stiffness (VMS), 3) Load Sharing Ratio (LSR), 4) Variation of Pressure Angle (VPA), 5) Maximum Principal Root Stress (MPRS), 6) Contact pressure (CPRESS).
To fulfill the research objectives a procedure has been developed, which is summarized into three main steps as shown in Figure 1. In the first phase, starting from the gear data, the model geometry is generated. In order to reach an adequate precision in the tooth geometry definition, specific software has been developed using MATLAB. This software computes the points of the tooth flank and root fillet and writes them to a text file in a format that CAD software (*ProE*) can read and import. The points are then interpolated using a *spline* in sketch mode of *ProE*. By means of common modeling techniques, the models of gear and the pinion are generated and then exported in a neutral format. Finally gear and pinion geometrical models are imported in *ABAQUS/CAE*. During the geometry import phase, some details can be misinterpreted, and then the imported geometry needs to be repaired by means of the ad hoc features. In order to use quadrilateral elements, the resulting geometry is then subdivided in quadrilateral regions, paying particular attention to their shape, as to say avoiding those that could lead the software to generate unacceptably distorted element. The results that are obtained from this method have been verified with experimental results and are in a good agreement.From the numerical results it is found that TE and VMS are influenced by profile modifications (PMs) amount, PMs shape, crowning and misalignment. LSR is affected by PMs amount and is not sensitive to PMs shape, crowning and misalignment. VPA is influenced by PMs amount and PM shape but not affected by crowning and misalignment. MPRS and CPRESS are affected by PMs amount, crowning and misalignment except PMs shape.

The present Ph.D thesis is dedicated to the study of near threshold fatigue crack propagation and fatigue strength under pure Mode III and Multiaxial Out-Of-Phase loadings. In particular two types of steel have been used (gear and bearing ones) for an estimation of micro flaws presence influence on fatigue strength and mechanisms governing fatigue propagation in the near threshold zone. The behavior of *`short cracks`* under shear loading has been studied by means of torsional and multiaxial out-of-phase tests carried out onto gear steel. First series of torsional tests carried out onto shallow micronotches of √area<1000 μm showed that torsional fatigue limits of gear steel material were higher than bending ones, due to the presence of shallow defects, see Figure 1.

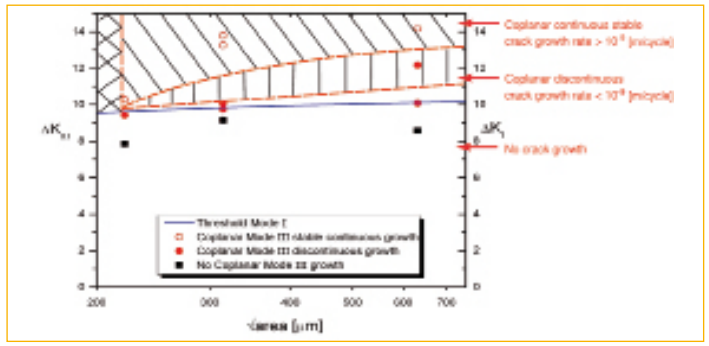


1. Fatigue limits in the presence of shallow micronotches, Mode I results vs. Mode III

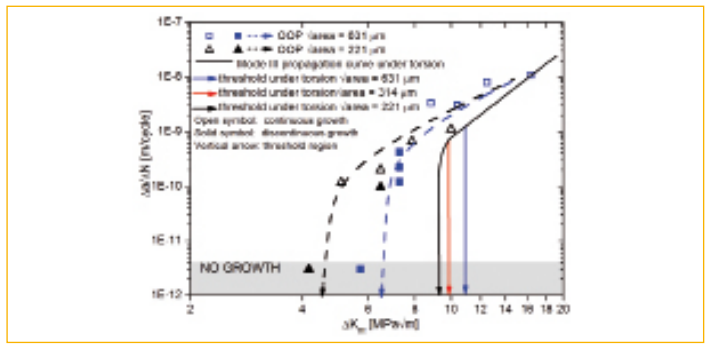
All broken specimens followed 45° branching mechanism of propagation (local Mode I). Run out specimens transverse sectioning of artificial defects revealed an evidence of coplanar shear crack propagation ahead of a micronotches, coexisting with Mode I one. Further torsional tests have been carried out onto shallow pre-cracks, by means of novel experimental procedures. Results of this tests confirmed that torsional fatigue limit is controlled by non-propagation condition of branched cracks. Due to the novel method it was possible to obtain stable coplanar growth from shallow pre-cracks of 200 μm < √area < 1000 μm, showing that $\Delta K_{III,th}$ is almost equal to $\Delta K_{I,th}$. The competition between two crack growth modes has been studied showing that Mode I growth was predominant due to the higher propagation rates in comparison with Mode III ones. The analysis of average crack propagation rates clearly confirm this fact, moreover, results of torsional fatigue tests confirmed definite existence of *`short crack effect`* for Mode III crack propagation under torsion. Figure 2 shows that results tend to show a strong dependence on defect size (higher than sensitivity of $\Delta K_{I,th}$ for the ΔK_{III} needed for a growth rate da/dN>10^{-9} m/cycle.

Multiaxial fatigue tests, simulating subsurface RCF loading pattern, were conducted in the presence of artificial shallow micro flaws. Experimental procedures proposed for the torsional tests onto shallow pre-cracks has been adopted. Results of this test campaign showed predominant shear mode crack propagation with almost complete suppression of Mode I growth due to the peculiar load pattern. Mode III fatigue cracks were able to propagate even at ΔK_{III} levels lower than $\Delta K_{III,th}$ obtained for pure Mode III, see Figure 3.

Application of the novel experimental procedures for a characterization of a commercial bearing steel has been made



2. Mode III thresholds for shallow precracks, short crack effect under Mode III vs. Mode I



3. OOP loading effect onto Mode III cracks threshold condition and *`short crack effect`*

for industrial research contract. Result of this research project proved that experimental method proposed is applicable for industrial needs, being able to improve performance of mechanical components via reliable predictions of material fatigue strength.
In particular results of bearing steel characterization revealed similar results with an evidence of fatigue effects obtained and observed during the gear steel assessment.

Summary of main results concluded in this doctoral thesis are:

1. caring out torsional tests with use of shallow pre-cracked micronotches it is possible to obtain thresholds also for small cracks, with √area < 1000 μm;
2. competition between propagation modes under conditions of pure torsion is won by Mode I due to the higher propagation rates in the comparison with Mode III;
3. stable co-planar Mode III growth in torsional tests is also observable at ΔK_{III} levels at which Mode III growth is much less rapid than Mode I and for the tested defects (220 μm < √area < 950 μm) $\Delta K_{III,th}$ is almost equal to $\Delta K_{I,th}$;
4. results tend to show a strong dependence on defect size (higher than sensitivity of $\Delta K_{I,th}$ for the ΔK_{III} needed for a growth rate da/dN>10^{-9} m/cycle;
5. out-of-phase loading (under stress conditions of sub-surface RCF) promotes co-planar growth by a flattening of crack surface asperities, and inhibiting Mode I propagation;
6. vi) $\Delta K_{III,th}$ under OOP is lower than the threshold obtained under pure Mode III tests (it also shows a *`short crack effect`*).