Chair:
Prof. Giampiero Mastinu

DOCTORAL PROGRAM IN MECHANICAL SYSTEMS ENGINEERING

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 located at the Bovisa Campus and in the Lecco Campus, in the Laboratory for Virtual Prototyping, 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.

- Severe shot peening to obtain nonostructured surfaces
- Mechanical measurement systems based on 2d and 3d image analysis: calibration techniques and uncertainty reduction
- Concept design and employment of a vehicle for eco races
- Dynamics and Diagnostics of rotating machineries
- Motorcycle dynamics and its interaction with the driver: numerical and experimental analysis
- Innovative solutions for improving pantograph dynamics and current collection quality
- Analysis of the nonlinear dynamics of a 2-axle freight wagon in curves

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

SEVERE SHOT PEENING TO OBTAIN NANOSTRUCTURED SURFACES

Process development and mechanical characterization of treated materials

Sara Bagherifard

Abstract:
Surface nanocrystallization of metal alloys by means of severe plastic deformation is a method to improve the mechanical behavior of structural elements. Among the ways to obtain a nanocrystallized surface layer, shot peening is one of the most promising processes, since it is applicable to very general geometries and to all metals and metal alloys without high-tech equipments.
The aim of this study has been the development of a severe shot peening process to obtain surface nanocrystallized metal alloys and to assess the mechanical properties of the obtained nanocrystallized surface with particular emphasis on fatigue behavior of the treated parts. This aim was fulfilled throughout the following main sections:

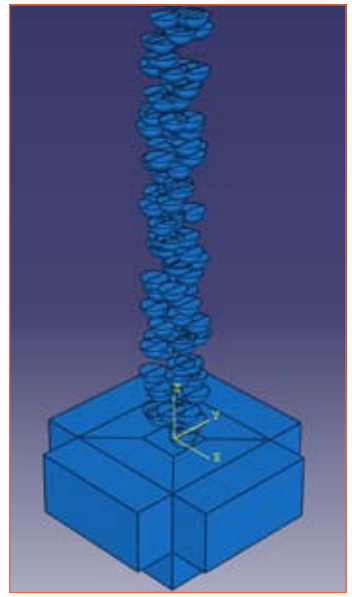
Studying the state of the art
The significance of shot peening application to obtain surface nanocrystallized materials is presented with an inclusive description of actual state of the art. Different shot peening methods which have proved to be able to create nanocrystallized layers are briefly described. The microstructural characteristics of nanocrystallized thin layers obtained with different processes are critically depicted. In addition, the influence of the process is reviewed on material behavior under different loading conditions. On this basis some possible addresses for developing the research in this field are drawn and underlined, including the necessity to focus on the application of air blast shot peening, that is the conventional shot peening method, to obtain nanocrystallized layers on steel alloys, Al alloys and nodular cast Iron which are all among the mostly used materials in industrial applications; and eventually the need for careful characterization of the treated specimen's fatigue strength is highlighted.

Numerical simulation of the process

Finite element simulation of air blast shot peening with unconventional parameters is performed to provide quantitative description of peening parameters' effect on the distribution and magnitude of residual stresses and also on the thickness of the work-hardened layer. The developed model is aimed to predict the treatment conditions that lead to surface nanocrystallization. The attention is focused on critical assessment of mesh convergence and the way the number of impacts can be related to the real treatment time and consequently to the resulting coverage. The results are critically discussed in terms of the induced residual stresses and surface work-hardening.
Studies performed to distinguish the essential parameters for structural evolution and generation of nanograins, have acknowledged large strains as the most important condition favorable to produce nanocrystallized surface layers. A method based on the criteria set on the accumulated equivalent plastic strain (PEEQ) value is proposed for estimation of the treatment parameters needed to obtain nanocrystallized surface layer and to assess its depth.
Comparison of the obtained numerical results with experimental data allow affirming that the model is a useful tool to predict generation of a nanocrystallized surface layer by severe shot peening and to relate the peening parameters to the treated surface layer in terms of residual stresses, work-hardening, and depth of the nanocrystallized layer. A view of the model used for multiple impact simulation with random shot sequence is shown in Fig.1.

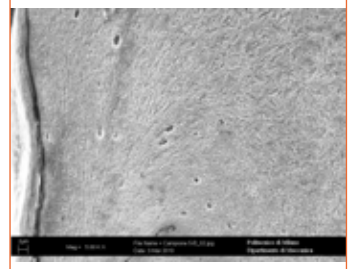
Execution of severe shot peening and characterization of treated materials

Severe shot peening method has been applied by means of standard air blast equipment but using peening parameters



1. 3D multiple random impact model

essentially different from conventional ones for the three chosen materials types. Different experimental processes including microhardness, roughness and X-ray diffraction measurements have been performed to characterize the treated surface of specimens. To obtain the trend of residual stresses, X-ray diffraction measurements have been carried out in depth step by step removing a very thin layer of material using an electro-polishing device. Microstructure observations were carried out through scanning electron microscopy (SEM) and transmission electron microscopy (TEM).



2. Cross-sectional SEM observation (500x) of a severely shot peened steel specimen

As presented in Fig. 2, generation of nanocrystallized layer over specimens' surface was confirmed by microscopy observations as well as in-situ high energy synchrotron X-ray diffraction grain size measurements.

Fatigue life assessment of severely shot peened smooth and notched specimens
Room temperature rotating bending fatigue tests are performed on not peened and severely shot peened smooth and notched specimens. With regard to smooth specimens, the results indicate improvement of fatigue life, notwithstanding the treated specimen's very high surface roughness; Different approaches have been applied to decrease the surface roughness of severely shot peened specimens. The best results have been obtained after repeening with smaller and harder shots: a refinement of treatment parameters aimed at reducing the surface roughness is proposed.
Shot peening is well-known to be more effective in increasing fatigue life of notched components compared to smooth ones. In order to investigate the effects of the proposed severely shot peened process, two series of notched specimens with a stress concentration factor of Kt=2 (common in machine elements like crankshafts and threaded components), including not peened and severely shot peened treated were fatigue tested. The results indicate significant fatigue life increment of 246% with respect to not peened series.

MECHANICAL MEASUREMENT SYSTEMS BASED ON 2D AND 3D IMAGE ANALYSIS: CALIBRATION TECHNIQUES AND UNCERTAINTY REDUCTION

Giorgio Busca

Fringe projection techniques are very popular thanks to their possible application in a lot of fields, such as industrial inspection, manufacturing, computer and robot vision, reverse engineering and medical diagnostics. The main qualities of these profilometry methods are non-contact and full field measurement, low cost and speed in obtaining the 3D information. One of the most used techniques is Fourier transform profilometry, which is based on the projection of a grid onto a surface and then viewed from another direction by a camera, which acquires the image. The object topography deforms the fringe pattern, the corresponding image is acquired on the camera sensor plane and then processed to obtain depth information.
The depth is extracted, through the Fourier-transform, from the phase difference between the grid projected on a reference plane and the same grid projected on the object surface.
In comparison with other fringe techniques, that require more than one image for the 3D measurement, the advantages of the FTP are elaboration speed and need of only one deformed image. On the other hand, it needs to resolve the projected grid lines individually, and consequently has a strong requirement on the pixel spatial resolution of the recording device. Moreover, FTP requires frequency domain filtering whose consequence is fine detail reduction and resolution loss.
Phase to depth conversion is possible by means of a suitable formula that depends on the geometric model of the acquisition system, i.e. its geometric parameters, and the carrier frequency of the grid. Obtaining the correct depth distribution is possible only if the geometric parameters are known. Theoretically the task is easy to be achieved, but in practise the estimation of these parameters is quite complex; for example the relative position between the projector and the camera cannot be fixed without a certain degree of uncertainty, but also the evaluation of the carrier frequency of the grid and the reference plane position is affected by errors. A calibration procedure is consequently necessary to overcome these limitations. Calibration methods proposed in literature till now may be distinguished in three categories: model-based, polynomial and neural networks.
In this thesis, two model-based approaches were proposed: the parameters estimation is achieved by a minimization algorithm of the mean squared error between the nominal depth of some planes placed at well defined positions and the result of the conversion formula (which depends on the chosen geometric model) applied to the phase obtained from the same planes.
Before introducing the calibration methods, the problem analysis was improved studying the effect of the uncertainty parameters estimation on the final result.
The question is how the uncertainty concerning the geometric parameters of the system (input parameters) can be extended to depth estimation (measurement output).
The answer may only come out from a sensitivity analysis of the calibration model.
The aim is the definition of a guide to uncertainty analysis about all the most common system setups to use in the design stage for the optimization of the measure uncertainty.
The sensitivity analysis of a Fourier-transform profilometry was performed both with the simple discrete derivative method, and the more complex global sensitivity analysis, based on Monte Carlo simulations.
Global sensitivity analysis is a powerful method that permits the evaluation of the uncertainty distribution from the input parameters to the output.
The quantification of the single contribution of every input parameters uncertainty onto to the uncertainty distribution of the system output, gives the opportunity to define a factor prioritization, i.e. which factor deserves further analysis or measurement, in order to improve the uncertainty of the estimated height distribution of the measured object.
The result of the analysis is a substantial description of the uncertainty propagation from which is possible to derive all the information related to a specific application of the system.
The aim obtained is the definition of a guide useful to quantify the measure uncertainty according to the application, i.e. different geometric disposition, and the chosen calibration procedure.
As explained before, the height information is extracted from the phase distribution through triangulation. This means that the relationship between the phase and height distribution depends on the system parameters such as the relative position of the projector and the camera, the fringe frequency and the reference plane position. It is possible to define the phase-to-height conversion with the determination of the system parameters, performing a calibration procedure.
In this thesis two novel calibration approaches were proposed. They use some calibration planes to calculate the system parameters.
The main innovation of these methods is the application of an exhaustive geometric model of the Fourier-transform profilometry that expresses the phase-to-height relationship in the most general way with a camera and a projector not aligned.
The geometric parameters are estimated with a least-square fitting between the phase-height data using the model equation. The goal reached with this method is a calibration based on a complete geometric measurement model that is not restricted to a limited volume, has a physic meaning easily comparable with the real system setup, and moreover allows for a simpler estimation process compared to a model-based one.
The first calibration method can be considered a hybrid between a model-based method, which identifies the system parameters characterizing the phase-to-height conversion formula, and a polynomial method, which finds the best fitting between the phase data and nominal position of several planes parallel to a reference one. It uses the phase data of parallel planes at known position to estimate the geometric values that permit the best fitting of the conversion formula to the phase-height data.
The tests show that the method is successful and robust.
The main advantage is the wide control on the system.
The measurement model has direct correlation with the physic problem, with no simplification assumptions. This permits to verify the estimation results and their physic meaning.
The method, as shown by the results, can estimate the parameters correctly with a low degree of uncertainty.
It is clear that an appropriate device for the planes placement is necessary in order to have the spatial coordinates, that may be used as references. Usually this is the principal limit of this kind of calibration methods, because it should be sufficiently accurate in order to guarantee an acceptable value of uncertainty in the calibration planes placement and along the whole measurable volume of the scanner.
The main innovation of the second calibration technique proposed is removing the hardware for the accurate positioning of the calibration planes. The information about the planes positions are obtained from the camera, which is already part of the scanner.
The task can be achieved only if the camera is previously calibrated. By comparing different camera calibration techniques available in literature the algorithm proposed by Zhang was chosen. It permits in the same time, the definition of the intrinsic parameters of the camera (focal length, optics aberration, central point's coordinates, skew factor) and extrinsic ones (camera position and orientation) described through the pin-hole model.
The procedure can be considered composed by two steps: in the first one the camera calibration process is performed in order to recover the position and orientation of each calibration plane, and in the latter, the scanner calibration procedure is completed. Both the steps were tested numerically and experimentally and in all the cases the reliability of the proposed calibration technique was demonstrated.

INNOVATIVE SOLUTIONS FOR IMPROVING PANTOGRAPH DYNAMICS AND CURRENT COLLECTION QUALITY

Marco Carnevale

The thesis proposes some methodologies to improve the dynamics of pantograph-catenary system, in order to reduce the variability of contact force and enable current collection quality. The variability of mean contact force, contact force spectral components related to the span passing and high frequency contact force components related to collectors flexural modes are taken into account in the work. The solutions proposed are applied to both single and double pantograph configuration. The instruments used are numerical analysis of pantograph-catenary interaction and laboratory experimentation on single components and on the whole pantograph. Furthermore, some of the proposed solution are verified by means of track tests along the Italian high speed line.
The mean contact force is affected by aerodynamic lift effects on the pantograph, which sum their contribute to the uplift force exerted by the actuator at the base of the articulated frame. This effect is different depending on the direction of incident air flow and on the position along the train, which affects the flow condition. The differentiated regulation of the uplift force at the bottom of the articulated frame enables to compensate this asymmetry of behavior and to obtain a regular mean contact force for all the pantographs and both train travelling directions. In the proposed solution a pneumatic pressure-controlled servo-valve driven by an electronic unit connected to the train data network supplies the pressure to the air spring with two different curves function
of speed and train orientation. The curves are defined on the basis of aerodynamic tests previously performed, having as target the T.S.I contact force. The possibility to control the contact force at span passing frequency by means of the control of the pressure in the air spring at the bottom of the articulated frame is analyzed exploiting the same servo-valve previously introduced. Experimental tests and numerical simulations are performed.
A model of the controlled pantograph is developed, trying to contain the complexity to the strictly necessary features, so to facilitate the simulation of the pantograph-catenary dynamic interaction.
The methodology of regulation of the uplift pressure for each pantograph and the model realized are used in a second part of the work to find suitable solutions for improving multiple pantograph current collection. A reduction of vibrations induced on the contact wire by the passage of the leading pantograph is shown to be beneficial for the performances of the trailing pantograph. This aim can be achieved either lowering the mean contact force of the front pantograph, as demonstrated by track tests, or controlling the uplift force at the span passing frequency as to reduce the uplift of contact wire in the middle of the span. The numeric results obtained for the span passing frequency control are experimentally validated on the hardware in the loop test bench of figure 1.

1. Test bench for hardware in the loop tests

Some actions can be taken on the trailing pantograph as well, increasing the mean contact force as to reduce contact losses, or controlling the uplift force at the span passing frequency as to contrast the contact force reduction in the middle of the span. The possibility to substitute the functionality of passive dampers placed on the primary suspension by means of the pressure-controlled servo-valve is also investigated by means of numerical simulations with a close-loop control using the velocity of the frame as feed-back signal. This part of the work would like to be a first step towards the implementation of active control on a real train set, since all the works found in literature consider the actuator as ideal.
In the last part of the thesis a passive control of high frequency vibrations related to the flexural modes of the collector is proposed. Shape memory alloy can be embedded in fiber-glass structure in order to develop a material with high damping performances and low weight. Martensitic structure shows high damping values increasing with the strain amplitude in a range of temperature compatible with railway standards, and in a range of strain compatible with the level of vibration of the collectors.
In the present work a first prototype of the lateral horn of the collector is realized with two patterned thin SMA layer embedded (figure 2) in order to show the effectiveness of the method.

2. Prototype of collector lateral horn with thin SMA layers embedded

The experimental results of non-dimensional damping obtained by decay tests for the horn with two SMA (CuZnAl) thin layers embedded (0.63%), compared to the results of the standard fiber-glass horn (0.4 %) and of a horn with laminas of commercial brass (0.42 %) show an effective increase of damping without relevant increase of weight or stiffness. Thank to their good structural properties the memory shape alloy material could be also embedded in the whole structure of the collector.
The approach taken in looking for possible solutions to the dealt problems means both to provide new concept to pantograph design, and to find solutions effectively implementable on a real vehicle without deep modification in pantograph structure, so that also pantographs already operating could be upgraded.

ANALYSIS OF THE NONLINEAR DYNAMICS OF A 2-AXLE FREIGHT WAGON IN CURVES

Egidio Di Gialleonardo

Rail transport is the most efficient mean, in terms of energy usage, of conveyance goods, however, the increased competition from air travel and trucks continuously requires to increase the capacity on modern freight wagons. Two-axle freight wagons represent highly nonlinear systems due to their cheap construction. Usually energy dissipation in the suspensions is obtained by means of friction elements which also makes these systems non-smooth. From a scientific point of view the analysis of the running properties of these wagons represents a challenge since the modelling of non-smooth systems is not consolidated in the railway community.
The innovative aspects of the work consist of the nonlinear analysis of the running dynamics of the vehicles in curves, which was partly left unexplored by previous research, and the quantification of the effect of the forces due to the coupling elements when the case of more than one wagon is considered.
In order to achieve the aims of the work the following steps have been taken:

- multibody modelling of the wagon including the nonlinear/non-smooth description of the behaviour of the UIC standard suspensions and the nonlinear/non-smooth aspects of wheel-rail contact;
- modelling of a group of two-axle freight wagons using existing models able to reproduce with sufficient accuracy the forces provided by the buffers and the draw gear. In this work, a group of three wagons has been considered;
- nonlinear analysis of the running properties in curves by means of maps of the steady-state solution reached after the negotiation of curve transition and bifurcation diagrams.

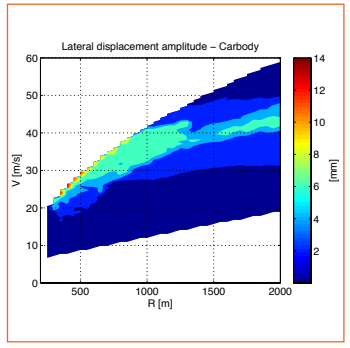
With regard to the model of the vehicle, the peculiarity of the system lies in the suspensions. The UIC standard suspension, shown in Figure 1, is made up of two parts: a leaf spring and a link system.
The deflection of the leaves yields the stiffness in the vertical direction whereas energy dissipation is introduced into the system by dry friction forces generated in between the leaves. The link system works as a pendular suspension system for the horizontal motion, yielding stiffness both in lateral and longitudinal directions.
Dry friction in the support of the link elements, which provides the necessary damping for the horizontal motion, is the only damping mechanism in the UIC suspension.
In order to reproduce with sufficient accuracy the nonlinear behaviour of the links a proper model of the system can be set-up. The model is characterised by a linear spring in parallel with elastic elements with dry friction, with the friction sliders obeying to Coulomb's friction law. Considering for example the longitudinal direction, the restoring force from the suspension is obtained by:

$$F_x(x) = -k_z x + \sum_{i=1}^{4} T_{ix}$$

$$\dot{T}_{ix}(\xi) = \begin{cases} -k_i \dot{x} & stick \\ 0 & slip \end{cases} \qquad (1)$$

depending on the state (stick/slip) of the friction slider.
The analysis of the single vehicle shows that the running properties of the two-axle freight wagons can be considered not satisfactory when narrow curves are negotiated at high speed values, since both the carbody and the trailing wheelset settle on a periodic attractor with large amplitude. On the contrary, considering the analysis performed on the group of three vehicles this behaviour is minimised, since the amplitudes of motion of the second vehicle, representative of any wagon in the middle of the composition, are significantly reduced, whereas with regard to the third vehicle, which represents the last wagon of the trainset, practically no oscillation is observed.
With regard to the running properties of the single vehicle in curves two different conditions are analysed, the tare and the fully-laden configuration. Curve radius varying from 250 m to 2000 m are considered, with a step of 50 m. For each curve radius simulations with different speeds are performed, in particular the minimum value corresponds to -0.8 m/s^2 cant deficiency whereas the maximum one corresponds to a value of 0.8 m/s^2.In Figure 2 a contour plot for the lateral motion amplitude of the carbody, reached after the negotiation of curve transition, is reported. The colours range from blue, corresponding to the smallest motion amplitude, to red, corresponding to the largest motion amplitude. In particular the minimum value is equal to zero, that is a stationary solution is found.
As far as the tare condition is concerned it is demonstrated that the running properties of the two-axle freight wagons can be considered not satisfactory when narrow curves are negotiated at high speed values, that still lie in the operating speed range. Under these conditions both the carbody and the trailing wheelset settle into a periodic attractor with large amplitude (up to 12 mm for the carbody and 6 mm for the wheelset).
It is shown that the periodic attractor is generated by a tangent bifurcation and the stationary solution loses its stability in a subcritical Hopf bifurcation. Furthermore, it is shown that the leading wheelset settles on a multi-periodic attractor when the vehicle negotiates a curve with 1000 m radius. The structure of this attractor is analysed in order to determine if it could be classified as chaotic. Since the motion is not sensitive to small changes of the initial conditions it is concluded that the motion is multi-periodic.
Considering a load on the carbody leading to the maximum admissible axle-load for these wagons, the dynamics of the wagon improves significantly, since both the carbody and the rear wheelset only settle on a periodic attractor characterised by relatively large amplitudes (up to 4 mm for the carbody and 3 mm for the wheelset) when large curves are negotiated at high speeds, that are not admissible under the normal operating conditions.

1. Standard UIC suspension



2. Map of the lateral motion amplitude of the carbody

The analysis performed on the group of three vehicles in tare condition shows that the effect of the coupling forces on the dynamics of two-axle freight wagons is important, since the amplitudes of motion for both the carbody and the trailing wheelset of the second vehicle, which is representative of any wagon in the middle of the composition, are significantly reduced compared to the ones obtained for the single vehicle. With regard to the third vehicle, which is representative of the last wagon of the trainset, practically no oscillation is observed.

CONCEPT, DESIGN AND EMPLOYMENT OF A VEHICLE FOR ECO RACES

Gianmarco Galmarini

The PhD thesis was sponsored by the Shell Eco-Marathon® (SEM) project of the Department of Mechanical Engineering of the Politecnico di Milano. "Shell Eco-Marathon®" is an international competition that involves participants to design and implement fuel-efficient vehicles. The challenge, whose first edition dates back some thirty years ago, more precisely to 1977, is aimed at students of universities and technical institutes across Europe.

Participating to a SEM race is a complex task and consists of both theoretical and practical activities. Two prototype vehicles have been designed, constructed and took part at the SEM competitions of the last three years with satisfactory results. The hydrogen vehicle A.R.T.E.M.I.De. (Fig. 1) and the solar vehicle Apollo (Fig. 2) were conceived, designed, manufactured and developed exploiting advanced design techniques and materials. Each part of these vehicles has been conceived for obtaining the reduction of consumption.

1. Artemide during race

The design started after preliminary experimental tests that were carried out on the wheels used for the competition. Such tests were performed on the RuotaVia test rig, a drum for tyres testing at the Laboratory for the Safety of Transport of the Politecnico di Milano. The results of the tests helped defining the structure of the wheels and of the whole vehicle. The preliminary design was based also on the tests carried out on motors, fuel cells and photovoltaic panels.
To achieve the goal of least consumption the activities were divided into two parts, namely the reduction of the rolling resistance, (tire rolling resistance, aerodynamic drag, …), and the increase of the efficiency of the powertrain. A preliminary optimization of the entire propulsion system and the race strategy waere performed at an early design stage.
The vehicle has been designed according with the rules of the SEM. Rear wheel steering, three wheeled vehicles were conceived and manufactured. The body shape (equal for Artemide and Apollo) was developed after aerodynamic considerations, starting from the optimized geometry of an axisymmetric body moving close to the ground. Additionally the body shape was modeled around the body of a (tiny) driver.
The body is a structural monocoque made in CFRP. Steering system is controlled by driver using two stick connected by a steel cable. Powertrain is composed by a DC motor connected to the wheel by a single step of gear reduction and e free wheel. Energy source can be simply a battery or a PEM hydrogen fuel cell (Artemide) or a photovoltaic panels (Apollo). A special design ECU controls the motor and manage race strategy. Every design activitiy has been integrated whit both a theoretical approach and experimental tests in order to choose the best solution for any subsystem.

The vehicles have taken part in competitions in France, Germany, England and in the United States of America. Satisfactory results (see Table 1) were obtained.

2. Apollo

VEHICLE	COMPETITION	RESULT	POSITION
Apollo	SEM Americas 2010	4560 km/l	1st (as guest team)
Artemide	SEM Europe 2009	2741 km/l	5th overall
Apollo	SEM UK 2010	7070 km/l	1st overall
Note: 7070 km/l is the absolute best performance in SEM competitions			
Note: Consumption is reported as an equivalent petrol consumption			

Table 1. Results of Artemide and Apollo at SEM races around the world.

After two years from the beginning of the project, the hydrogen prototype Artemide holds the fourth position in the ranking for hydrogen vehicles at the Shell Eco Europe-Marathon, the solar prototype Apollo won both the Shell Eco-Marathon Americas (guest team) and the SEM UK. In addition Apollo set a new absolute primacy of least consumption at the Shell Eco-Marathon® competitions.
Other relevant results obtained at the SEM races are "BOSCH® Technical Innovation Award" at SEM EU 2007 and "AUTODESK® Design Award" at SEM EU 2009.

The thesis is subdivided into six main parts.

1. Conversion of the early prototype vehicle "Why Not" in a fuel cell electric vehicle. This operation was essential for the subsequent design of Apollo and Artemide prototypes. Theoretical development for subsequent engineering activities.
2. Conceptual design of new prototypes considering ergonomics and rolling resistance.
3. Definition of the optimum geometry of the vehicle by means of fluid dynamic analysis. Actual tests have validated CFD analyses. An experimental test campaign was carried out in the Wind Tunnel of the Politecnico di Milano on the actual vehicle.
4. Design of the body of the vehicle (structural design). The body was made from carbon fiber reinforced plastic, by a finite element analysis the best layout of fibers was carried out. The embodiment design and the construction of the models and molds of the vehicle body was performed. The whole body was constructed according with the results of CFD and FEM analysis, SEM rules specification and using a low cost production process.
5. Design of the major subsystems fitted into the vehicle. These subsystems have been developed through test benches, experimental test or through the use of topological optimization software.
6. Development of a simulation code to model the behaviour of the vehicle running at the various race tracks (such a code was useful both during vehicle design and to found the best race strategy).

SUMMARY OF DYNAMICS AND DIAGNOSTICS OF ROTATING MACHINERIES

Roberto Ricci

The characterization of the dynamical behavior of mechanical systems and components is an important topic of study both in scientific and industrial field. Since mechanical systems are complex and composed of different types of components, the research activity was focused on the dynamics of rotating machines and rotating components.
The characterization of the dynamical behavior of this kind of machines is useful for the definition of both the behavior of the system and its condition.
Since the dynamics of real systems can be defined on the basis of the measure of experimental signals acquired during their operation, the original implementation of advanced signal processing techniques has been performed. Therefore, time synchronous average (TSA), frequency demodulation, cepstrum, wavelet transform, II order ciclostationarity, empirical mode decomposition (EMD), envelope analysis and spectral kurtosis have been implemented.
This methodologies allowed carrying out diagnostics approaches for gearboxes and rolling bearings.
The effectiveness and applicability of the approaches has been also tested with good results in industrial field for the diagnostics of the high speed trains traction system.
The performed diagnostics allows the realization of a *Condition-Based Maintenance (CBM)* and can be developed to perform prognostics.

1. Rotating components considered in the research work: gearboxes (left) and rolling element bearings (right)

The evaluation of the dynamical behavior of a rotating machine or a rotating component can be also realized by means of numerical models (*model-based diagnostics*): in this case, sound and reliable finite element models are required. The optimization of rotating machines models is performed by means of a *model updating* process. From a general point of view this process is based on the minimization of an error function which describe the difference between the model and the real machine.
During the research activity, the original implementation of a model updating process working on different algorithms was performed. Two iterative algorithms, exploitable both in separated and complementary way, have been considered: a mathematic-deterministic and a random-stochastic methods. The implemented algorithms have been applied on models of machines working in Italian power plants and subsequently used for the optimization of models of Electricité de France machines during a research project.
The obtained results have been encouraging and allowed, on one hand, the evaluation of the algorithms performances and on the other hand the realization of a suitable tool for rotating machineries models optimization. It is worth noting indeed that the model updating process assumes a great importance in industrial field for both rotating machines manufacturers and users.

3. Example of power plant rotating machinery

Moreover a particular case related to the dynamics of rotating machines was considered during the research activity: the dynamical instability due to transverse crack. This problem has been treated for the first time some decades ago and solved by Floquet's theory. A lot of papers have been realized about this topic but all the works were based on the application fo the Floquet's theory to the Jeffcot's rotor. The use of a simple model was mainly due to the unavailability of algorithms for the application of the Floquet's method to complex and more reliable rotating machines models. During the research activity, suitable algorithms for the realization of Floquet's analysis on complex models were implemented. In this way the Floquet's analysis has been applied, for the first time, to a real rotating machine model.
The obtained results allow drawing important conclusions, different from those shown until now in literature: conversely from the analysis performed on Jeffcott's rotor, dynamic instability seems not depending from the rotational speed. In general the stability of the real rotating machinery is guaranteed for whatever condition of rotational speed and depth of crack.
This results represent a certain progress in scientific research and assumes great importance from a industrial point of view.

3. Rotor transverse cracks in power plant of rotating machinery.

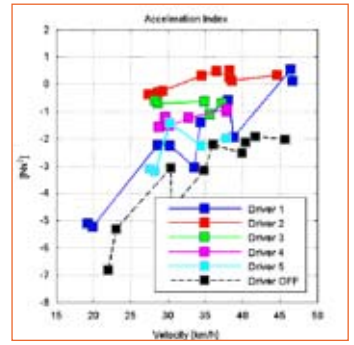
MOTORCYCLE DYNAMICS AND ITS INTERACTION WITH THE DRIVER: NUMERICAL AND EXPERIMENTAL ANALYSIS

Emanuele Ruspini

The present work analyses the study of motorcycle stability and the rider influence on the vehicle dynamic behaviour. Statistical analyses show that the dynamic instability of vehicle during driving is often the cause of accidents, thus the study of the stability of the vehicle has a direct role for the safety of the rider and passenger. Furthermore the inertial properties of the rider are similar to the motorcycle properties so it is important to study the interaction between driver and vehicle during driving.
During the research activities, numerical models for simulations and experimental tests, both in-door (with a test bench) and out-door (on urban road and track) are used. With the aim to study the running stability of the two wheeled vehicles, numerical models for simulations are developed and customized to reproduce the behaviour of the vehicle studied.
During the experimental tests a sport motorcycle is used to execute several manoeuvres; the motorcycle used is the F4-RR312 manufactured by MV Agusta s.p.a. this vehicle was fully instrumented during the research activity (see figure 1) to allow the study of running stability, the motion law of vehicle and the position of driver during the execution of several manoeuvres.
In the first part of the thesis, the vehicle stability is studied with the use of a test bench. With a test bench is possible to obtain repeatable test conditions, furthermore the use of a test bench allows to operate in safety condition and the execution of tests is quick and cheap.
The used test bench locks the vehicle in correspondence of the pivot of the rear suspension; the linkage allows the rotations of vehicle (yaw, roll and pitch) and it limits the translations. Two motor rolls are present on the test bench to impose the equivalent running velocity, the motor rolls are positioned under the vehicle wheels.
The vibration–modes of the vehicle on the test bench are experimentally estimated; the link between the vehicle and the test bench, reducing the capability of vehicle to move, modifies the shape and frequency of the vibration–modes with respect to the condition of vehicle running on the road.
A numerical model to reproduce the vehicle behaviour including the effects of the constrain between the test bench and the vehicle was set up using the results of the experimental tests.
In the second part of the thesis, a methodology for the identification of the vibration-modes involved during driving (weave and wobble) and for the computation of the safety margin is proposed.
The proposed methodology is applied in two different ways: with the aim to analyse the experimental tests to investigate the effect of the regulation of some parameters on vehicle stability and with the aim to develop an on-board system to warn the driver about possible dangerous situation during driving.
The running condition of vehicle, in terms of damping factor of weave and wobble modes, is defined observing the main quantities related to the vehicle instabilities. The quantities used are the steer angle and the lateral acceleration; these parameters are easily measurable during running and they provide a complete information about vehicle running condition.
The proposed methodology continuously esteems the vibrating – frequencies and the damping factors of weave and wobble modes with the use of fast identification methods (i.e. Half-Power Bandwidth Method).
When the fast methods find a reduction at least of one damping factor value, the parameters estimation is repeated using the more accurate Prony's Method.
The results obtained are compared to several thresholds for each mode, these values denote different dangerous situations and are used to inform the driver. In figure 2 is shown the logical scheme of the proposed methodology.
It is possible to apply this methodology to investigate the effects of some vehicle parameters (i.e. hydraulic regulation of suspension, steering damper) on vehicle stability. The analysis is carried out "Off-line" post-processing the experimental data and studying the variation of the frequencies and of the damping factor associated to each mode when some parameters are modified. Experimental tests are carried out to investigate the influence of suspensions, steering damper and tyres pressure on vehicle stability. The manoeuvres are reproduced using a numerical model and the results are compared to the experimental result giving good agreement.
In the last part of the thesis, the driver behaviour is studied during the execution of different imposed manoeuvres.
The vehicle motion are obtained from the measurements of the instrumented vehicle used during tests, moreover the driver motion is evaluated analysing the frames recorded with an on-board cam and applying an innovative vision technique.
The driving style and the actions of drivers with different skills are studied and estimated relating the vehicle motion law with the motion and actions on steer system make from drivers. The study is conducted considering the time delay between the driver actions and calculating several synthetic indexes representing the behaviour of vehicle and of driver in steady state and transient condition (i.e. in figure 3 the Acceleration index for every driver is reported).
The driver behaviour has been studied considering both manoeuvres in steady state condition (the execution of a steering pad) and in transient condition (the execution of a double lane change); the manoeuvres were repeated considering different speed profiles.

1. Instrumented motorcycle used during the experimental tests

2. The logical scheme of the proposed methodology



3. Acceleration index