INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

SURVISHNO

SURVEILLANCE
VIBRATIONS
SHOCKS
NOISE

Vibes in action

8-10 JULY 2019
INSA LYON

Abstracts

BOOK OF ABSTRACTS

SURVISHNO 2019

A joint organisation of the conferences
Surveillance, Vibration Shock and Noise, and
Experimental Vibration Analysis

General Chair : J. Antoni, D. Rémond

Table of contents

Monday

Angular approaches

Cyclo-non-stationary analysis for bearing fault identification based on instantaneous angular speed estimation

Edgar F. Sierra-Alonso * [1,2], Jérôme Antoni [1], Geman Castellanos-Dominguez [2]

[1] Institut national des sciences appliquées de Lyon – Institut National des Sciences Appliquées (INSA) - Lyon – France
[2] Universidad Nacional de Colombia (COLOMBIA) – Colombia

To identify a rolling element bearing (REB) failure under variable speed is mandatory to deal with highly non-stationary conditions, mainly caused by the variation of the speed, due to for REB failures the failure frequency is a function of the angular speed. Making the Instantaneous Angular Speed (IAS) one of the most important parameters to measure. However, the speed measurement is sensitive to disturbances like loss of samples or artefacts (Zimroz, R. et al.). Alternatively, the IAS can be extracted directly from the vibration signal, where this is the most challenging situation. Due to the multi-component nature of the signal, where different families of harmonics may coexist, alongside with the interaction between the orders and the structural resonances of the machine, and the low Signal to Noise Ratio (SNR) where noise comprises any component in the signal which is not of direct interest for the analysis (Leclere, Q et al.). As evidence of the continuous interest in REB fault detection under variable IAS, the subject was recently addressed in (Antoni, J., et al.); where two tasks are identified: the IAS extraction from the vibration signal and the posterior failure detection in the angular domain, a domain where the failure identification is possible only after a successful extraction of the IAS. As we will deal with low SNR our approach must be robust. For such reason, it is proposed the use of a Short-Time Non-Linear Least Squares (STNLS) method to estimate the IAS, if a signal is stationary in a short-time segment.
The second step is to highlight a REB failure under variable speed under highly non-stationary conditions. Recently, (Abboud, D. et al.) propose an extension of the cyclic spectral correlation for a time-varying speed scenario. However, it is assumed that time-dependent components are independent of the operating speed, which may be acceptable for modest speed variations; thus, its compensation constitutes an emerging field of investigation. Therefore, a methodology using a Short-Time/Angle frequency 2D filter based on Spectral Kurtosis (STSK), will be proposed in the present work, given that a signal it is expected to be piece-wise stationary regardless the domain (time or angle) if a window small enough is considered. The robustness of the STNLS method is tested in a simulated signal contaminated with different levels of two different types of noise (pink and white). Finally, the STNLS and STSK are applied in a case of study of an aircraft engine publicly available in (Antoni, J. et al.).

Zimroz, R., Urbanek, J., Barszcz, T., Bartelmus, W., Millioz, F., & Martin, N. (2011). Measurement of instantaneous shaft speed by advanced vibration signal processing application to

*Speaker

wind turbine gearbox. Metrology and Measurement Systems.

Leclere, Q., André, H., & Antoni, J. (2016). A multi-order probabilistic approach for Instantaneous Angular Speed tracking debriefing of the CMMNO 14 diagnosis contest. Mechanical Systems and Signal Processing.

Antoni, J., Griffaton, J., André, H., Avendaño-Valencia, L. D., Bonnardot, F., Cardona- Morales, O., ... & Sierra-Alonso, E. F. (2017). Feedback on the Surveillance 8 challenge: Vibration-based diagnosis of a Safran aircraft engine. Mechanical Systems and Signal Processing, 97, 112-144.

Abboud, D., Baudin, S., Antoni, J., Rémond, D., Eltabach, M., & Sauvage, O. (2016). The spectral analysis of cyclo-non-stationary signals. Mechanical Systems and Signal Processing, 75, 1–21.

Investigation of the Influence of the Operating Parameters on theMagnetic Encoder Geometric Error Compensation

Halil Ibrahim Cakar * [1,2], Ilyes Khelf , Hugo André *

3

[1] ECAM Lyon – ECAM Lyon – France
[2] Laboratoire dÁnalyse des Signaux et des Processus Industriels – Université Jean Monnet [Saint-Etienne] : EA3059 – France
[3] Laboratoire d'Analyse des Signaux et des Processus Industriels (LASPI) – Université Jean Monnet - Saint-Etienne : EA3059 – France

The encoder is the only sensor needed to perform Instantaneous angular speed (IAS) analysis, an alternative technique used to monitor gears, bearings or other electro-mechanical elements. The encoder is subject to an intrinsic defect called Geometric Error (GE). Although it has various origins, GE can be simplified as being related to the variable angular size of every encoder segments forming the theoretically uniform pattern. As a result, GE introduces a cyclic perturbation observed on the spectrum of the estimated IAS. These perturbations exhibit a first order cyclostationary behaviour which replicates themselves in each revolution of the shaft. Since the impacted frequency channels can also be studied to monitor the health status of the shaft line, GE should be corrected for a better IAS estimation.
In this study, a rotation domain averaging based algorithm is developed to compensate the GE of the estimated IAS signals. The GE signature of a given signal is estimated and is used to compensate the GE of the other signals as well as itself. The term cross-correction is introduced to mention the correction of signals with each other's GE signature. The quality of the correction is analysed and is shown that it depends on several operating conditions. In other words, signals obtained for certain operating conditions are shown to be better at correcting GE than signals obtained for different operating conditions.

The developed algorithm is tested on a 2-MW wind turbine campaign which is instrumented with a magnetic encoder. These observations makes it possible to qualify the properties of the best GE corrector signals and dress an optimized correction algorithm suitable for any database. Since there were several interventions on the wind-turbine like re-installation of the encoder, gearbox change and gear defect, it is also possible to observe the influences of these interventions on the GE compensation.
The results of this work are expected to be useful for gearbox operators as it represents a probable solution for early fault detection especially in demanding operating conditions.

*Speaker

Interpolation of periodic hidden signal measured at steady-operating conditions on hydroelectric turbine runners

Quang Hung Pham * , Martin Gagnon [1], Jérôme Antoni [2], Souheil-Antoine Tahan [3], Christine Monette [4]

[1] Institut de recherche d'Hydro-Québec – IREQ 1800 Boul. Lionel Boulet Varennes (QC) J3X 1S1, Canada
[2] Institut national des sciences appliquées de Lyon (INSA Lyon) – INSA Lyon – 20 Avenue Albert Einstein, 69621 Villeurbanne cedex, France
[3] Ecole de Technologie Supérieure (ETS) – 1100, rue Notre-Dame Ouest Montréal (Qc) H3C 1K3 Canada, Canada
[4] Andritz Hydro Canada LTD. – Canada

Stress levels play an important role in the fatigue reliability evaluation of hydroelectric turbine runners. However, due to high costs and time required for the instrumentation, the experimental strain measurements on runners are limited. Thus, we cannot completely obtain the dynamic stress applied on runners over all the possible operating conditions, which could lead to an inaccurate evaluation of fatigue damage. Therefore, our research aims to use existing data measured by strain gauge to interpolate the unknown or not measured information about runner stress at all the steady states of hydroelectric turbines. At steady-operating conditions, a strain signal, measured on the runner, can be separated into two principal components: periodic and stochastic. The periodic phenomenon hidden in the signal is linked with synchronous rotation speed of the turbine and is extracted by the synchronous average method as the first order cyclostationary components. This paper presents the first step of our research that extracts and interpolates this periodic part at steady-operating states. A case study is used to compare two different kriging interpolation methods: the Spatial Kriging Method (based on 2D variogram) and the Spatio-Temporal Kriging Method (based on 3D variogram). The initial parameters are obtained from the strain gauges installed on a Francis turbine runner measured over a set of steady operating conditions. The interpolation results are then compared and validated in this paper with the experimental values. Finally, recommendation is proposed to select the most suitable method for further interpolations of other complex components of runners strain signals such as the non-synchronous and stochastic ones.

*Speaker

Adaptive tacho information estimation for surveillance of rotatory machine under nonstationary conditions

Yi Wang * [1,2], Bingchang Hou [1], Baoping Tang [1], Yi Qin [1]

[1] College of mechanical engineering, Chongqing university – China
[2] Chongqing University – China

Rolling bearing faults are the leading causes of downtime in rotary machines. In recent years, numerous and various vibration-based approaches have been put forwarded for rolling bearing fault detection. In the vibration-based techniques, order tracking-based methods are considered as very effective techniques. In the current reported order tracking methods, auxiliary devices are essential to obtain the instantaneous angular speed (IAS) of the machine. Aiming at this shortcoming, estimating IAS from vibration signals has been studied and some tacho-less order tracking (TLOT) techniques have been put forwarded. However, the effectiveness of the current available TLOT algorithms rely on the manually selection of the initial parameters for IAS estimation, which bring about user-friendliness. In order to tackle the aforementioned obstacles, a novel adaptive tacho information estimation method based on nonlinear mode decomposition (NMD) is proposed. In the proposed method, the nonlinear mode decomposition (NMD) method is improved and its computational burden is reduced. And then, the tacho information is adaptively estimated. The vibration signal collected from an aircraft engine is used for signal analysis and the effectiveness of the proposed is successfully validated.

*Speaker

Diagnostics and Dynamic models

Characterization of a Bouc-Wen model-based damper model for automobile comfort simulation

Hanwei Gao * [1,2], Louis Jézéquel [3], Eric Cabrol [2], Bernard Vitry [2]

[1] Laboratoire de Tribologie et Dynamique des Systèmes – Ecole Centrale de Lyon, Ecole Nationale des Travaux Publics de l'Etat, Ecole Nationale d'Ingénieurs de Saint Etienne, Centre National de la Recherche Scientifique – France

[2] Technocentre Renault [Guyancourt] – Renault – France

[3] Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) – CNRS : UMR5513, Ecole Centrale de Lyon, Ecole Nationale d'Ingénieurs de Saint Etienne – 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France

Ride comfort is considered as one critical focus for a chassis system. To ensure a satisfying comfort performance of a vehicle in development, a detailed damper characterization needs to be pre-defined in the early phase of project with the help of simulation results in virtual proving ground. However, the current damper model integrated in whole vehicle simulations is sometimes difficult to fit to test results due to its over-simplifications especially in low speed excitation regimes. Thus this article proposes an enhanced shock absorber model to improve simulation predictions without increasing substantially calculation costs. The parameterized model is mainly based on a Bouc-Wen model considering its capability of reproducing highly nonlinear hysteretic phenomenon. Other components such as a velocity-dependent switch have been included to reproduce the asymmetrical curve in compression and rebound phases. In order to identify the parameters, firstly a multi-objective optimization using NSGA-II algorithm has been applied based on the measurements under sinus signals. The excitations on test bench have been separated into several groups according to the forms of their force-velocity curves. The objectives are to achieve the minimum error corrections for each group. As a result, an optimum set which represents the best trade-off between the objectives is obtained and form a Pareto front. By analyzing the solutions included in this front, the best-fit intervals of parameters can be revealed. Secondly weighting factors can be decided for each objective in order to choose proper optimums from the front according to different frequency regime orientations of simulation conditions. Finally comparative examples in virtual proving ground show that the correction quality is well improved for chassis' comfort prediction using the proposed model. This example demonstrates the effectiveness of the modeling and its potential in comfort improvement with the help of design of experiments.

*Speaker

Modal identification of machining robots

Asia Maamar * [1], Vincent Gagnol [1], Laurent Sabourin [1], Thien Phu Le [2]

[1] Université Clermont Auvergne, CNRS, SIGMA Clermont – Université Clermont Auvergne, CNRS, SIGMA Clermont, Institut Pascal – France
[2] Université d'Evry Val-d'Essonne – LMEE, Univ Evry, Université Paris-Saclay – France

The requirement of high performance in the industry have led to the introduction of industrial robots in the machining field. Machining robots have become a potential and promising alternative to standard machine tools because of their important workspace and their high flexibility in the machining of complex parts. However, their lack of precision and rigidity is still a limit for precision tasks.
Therefore, the modal identification of a machining robot is important for an accurate knowledge of its dynamic behavior. Usually, the characterization is carried out through an experimental modal analysis. However, the excitation, artificially, created by a hammer or a shaker is not representative of the real cutting force applied in machining. These tests are thus performed in rest. Unfortunately, the dynamic behavior of a machining robot in rest differ significantly from that identified in service.

In this paper, an experimental modal analysis of an ABB IRB 6660 robot is firstly investigated. Then, modal parameters are identified during a machining operation through an operational modal identification. A significant variability of modal parameters identified at rest from those identified in service is observed, which explicates the great need to identify modal parameters in operational machining conditions.
Keyword: Experimental modal analysis, Operational modal analysis, machining robots

*Speaker

Demodulating of the 3-D tip clearance of turbine blades using BP neural network optimized by genetic algorithm

Hongcheng Liu * [1], Xiaodong Zhang [1,2], Yiwei Xiong [1], Siying Xie [1]

[1] School of Mechanical Engineering - Xi'an Jiaotong University – China
[2] Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System – Xi'an Jiaotong University – China

The traditional tip clearance of aero-engine is a one-dimensional variable signal, which contains poor fault information of turbine blades. In contrast, the three-dimensional (3-D) tip clearance of the aero-engine contains more abundant fault information, which can reflect the fault features of turbine blades more intuitively and comprehensively. The typical faults of turbine blades such as thermal fatigue and crack can be diagnosed based on three-dimensional tip clearance. Therefore, an optical fiber probe with three two–circle coaxial bundles based on intensity modulation is used to obtain three-dimensional tip clearance. The voltage signal collected by a single unit of the optical fiber probe is modulated simultaneously by the distance and the inclination angle between the probe end face and the measured surface, therefore it is difficult to demodulate three-dimensional tip clearance from output signal of the optical fiber probe. In this paper, an approach for demodulating of three-dimensional tip clearance of turbine blades is presented using BP neural network optimized by genetic algorithm. Three voltage ratios and three-dimensional tip clearance are used as input and output of BP neural network, respectively. Optimizing the weights and thresholds of BP neural network by genetic algorithm makes the prediction output of BP neural network more accurate.The high dimensional and nonlinearity problem between the optical probe output voltage signal and three-dimensional tip clearance can be solved by this approach. The training and test data is obtained through static calibration bench such as Fig.1 and the data is preprocessed to ensure its reliability and accuracy. Experiment results show that this demodulating approach has good precision, which can fulfil the requirements of three-dimensional tip clearance detection and provides a powerful guarantee for the fault diagnosis of turbine blades.

*Speaker

Research on the Variation Mechanism of the 3-D Tip Clearance of a Cracked Blade under Multi-parameters in the Aero-engine Acceleration Process

Yiwei Xiong * [1], Xiaodong Zhang [1,2], Siying Xie [1], Hongcheng Liu [1]

[1] School of Mechanical Engineering - Xi'an Jiaotong University – China
[2] Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System – Xi'an Jiaotong University – China

The turbine blade crack is the most typical fault of the aero-engine. The blade crack fault will lead to three-dimensional (3-D) spatial characteristics of the blade tip clearance, such as Fig.1 (a). Compared with the traditional vibration signal, the 3-D tip clearance contains more abundant fault information of the turbine blades, therefore, the research on the variation mechanism of the 3-D tip clearance is of great significance for the crack fault diagnosis of the turbine blades. However, previous researches only focused on the steady state condition of the aero-engine, lacking consideration of the aero-engine acceleration process, which has a significant effect on the blade crack fault. Therefore, in order to investigate the variation mechanism of the 3-D tip clearance of cracked blades in the aero-engine acceleration process, a numerical model of the high pressure turbine, including the turbine blade and disk, is established. In the acceleration process, the centrifugal load, thermal load and aerodynamic load of the aero-engine are varied with time, which are considered in this model. Besides, the cracks are added to the trailing edge of the turbine blades, and the blade cracks with different length and location are analysed. The deformation vectors of the blade tip surface are obtained through a finite element method, and then the variation of the 3-D tip clearance of the cracked blades can be calculated, such as Fig.1 (b). The results show that there are some clear distinctions in the 3-D tip clearance between normal blades and cracked blades, which can reflect the blade crack information accurately and effectively. In conclusion, the 3-D tip clearance can provide abundant fault information for the state monitoring and fault diagnosis of the aero-engine turbine blades, laying a theoretical foundation for the fault diagnosis of the turbine blade crack based on the 3-D tip clearance.

*Speaker

Jointed Structures

Identification through Frequency-Domain Methods of Hysteretic Models for Bolted Joints of Assembled Structures

Rafael Teloli * [1]

[1] São Paulo State University (UNESP) - Faculdade de Engenharia de Ilha Solteira – Brazil

Assembled structures play an essential role in dynamic structural applications. However, the nonlinear interactions that occur in the joint interface are complex and challenging for modeling mainly due to the customarily hysteretic effect generated in these spots. Therefore, some contributions still lacking in the literature to analyze the dynamic behavior and to predict the structural properties on the joints. Hence, this article proposes to apply and to compare both the harmonic balance method and the harmonic probing technique to update parameters from experimental measurements for a beam structure with bolted joints operating under nonlinear regime of motion. The main novelty of this work lies on performing a nonlinear modal analysis of the assembled structure through frequency domain methods when the excitation assures a weak hysteretic force. An experimental setup composed of two substructures, both made of aluminum and connected by a bolted joint, is used to identify the nonlinear frequency response functions from the measurement data and then to extract the model parameters. The Bouc-Wen model is adapted to create a nonlinear mathematical model that represents the hysteretic effect in the joint interface, since the model can achieve a wide range of states of hysteresis loops analytically. The updated numerical models obtained from the two different strategies are also correlated with experimental data. The results show that the frequency domain methods provide a useful and straightforward approach for nonlinear updating of hysteretic models for assembled structures by bolted joints.

*Speaker

Fixed point Algorithm resolution and model reduction for jointed structures dynamic simulation.

Anthony Meurdefroid * [1], Nicolas Peyret [2], Gaël Chevallier [3]

[1] Laboratoire QUARTZ - SUPMECA EA 7393 – SUPMECA Paris – France
[2] Laboratoire QUARTZ-SUPMECA EA 7393 – Laboratoire QUARTZ EA 7393 - SUPMECA Paris, 3 rue Fernand Hainaut, 93400 Saint Ouen, France – France
[3] Franche-Comté Électronique Mécanique, Thermique et Optique - Sciences et Technologies (UMR 6174) – Université de Franche-Comté – France

The bolted joints have a strong impact on the damping and the stiffness of the structures. This impact remains difficult to predict because of the difference between the length scale of the real contact area and the wavelength of the vibration modes, and the uncertainties on the real geometry of the contact area. The method proposed in this paper is to divide the jointed structure into two parts: the linear part (L) and the non-linear one (NL) located around the joint. First, a linear analysis is performed on the global structure, neglecting dissipation inside the joint, to determine the normal modes of the structure. The normal modes subspace is normalized to the stiffness matrix to associate to each eigenvectors the same strain energy. In the neighborhood of the bolted joint, eigenmodes are not orthogonal one to each other's. Thus, it is possible to reduce the size of the subspace spanned by the local eigenmodes. Moreover, most of them do not dissipate energy. Thus, it is possible to select the most dominant ones, i.e those that induce non-linear behavior in the joint. We introduce the Principal Joint Strain Basis (PJSB) which is the optimal Ritz basis deduced from the structure eigenmodes, and simplified thanks to the analysis of the dissipation potential of each eigenmode. The dissipation potential is estimated by the energy coupling in the joint computed from the sensitivity of the eigenfrequency to the tightening configuration, i.e. when the surfaces of the interface are tied or when the tightening is very low. Then, we assume that a meta-model is able to represent the behavior of the joints. In order to build it, we apply the PJSB as a loading on a finite element model of the joint and we post-process the results in order to use them in a reduce order model. Different strategies of resolution are proposed, depending on the number of modes selected.
In order to guarantee the numerical stability of the proposed scheme, it is then essential to set up a relaxation (or damping) method by modifying the formulation at each iteration (Gauss-Seidel form). This consists in introducing a parameter which makes it possible to determine the new state by weighting the value of the predicted state and the one of the old state. This relaxation method will also be coupled with an Aitken type acceleration method. The theoretical frame proposed in this paper allows to simulate at a lower cost the dynamic behavior of the assembled structures. The metamodel method presented is very efficient, in particular, when several modes load the connection in the same way or several connections are loaded in the same way.

*Speaker

MODELLING THE DAMPING AT THE JUNCTION BETWEEN TWO SUB-STRUCTURES BY NON-LINEAR MODELS : IMPROVING THE MODEL AND THE RESOLUTION

Veronique Kehr-Candille * [1]

[1] ONERA, Department of Material and Structures, Chatillon – ONERA – France

We are interested in the modelling of the damping at the level of the junction between two substructures. In previous works [1],[2], we have represented the connection by a simplified model, which takes into account both dissipative and non-linear aspects of the junction. We used Bouc-Wen and Dahl models, which were adapted to be inserted in a finite elementsystem. In the present work, we use the generalized Iwan-Jenkins model (combination of springs and dry friction elements). This model makes it possible to better simulate non-linear damping behaviours observed in experiments. Moreover, the differential system obtained with the Iwan-Jenkins model, can be solved using the notion of sub-differential, which is a powerful mathematic tool to solve non-smooth differential systems [3], [4].

The initial tool presented in [3] is adapted to solve differential systems with several degrees of freedom. Numerical simulations including the Iwan-Jenkins model are presented. A comparative study between different algorithms (Runge-Kutta, differential inclusions) is shown. A comparison between numerical simulations and experimental results is also presented.

V. Kehr-Candille, Modelling the Damping et the Junction between Two Substructures, Journal of Aerospace Lab, Issue 14 (September 2018)

V. Kehr-Candille, Identification of hysteretic systems for damping modelling, proceedings of ISMA 2018 International Conference on Noise and Vibration Engineering, september 2018, Leuven (Belgium)

C.L. Lamarque, J. Bastien, F. Bernardin, Non-smooth Deterministic or Stochastic Discrete Dynamical Systems, ed. Wiley (2013)

J. Bastien, G. Michon, L. Manin, R. Dufour, An analysis of the modified Dahl and Masing models : Application to a belt tensioner, Journal of Sound and Vibration 302(2007) 841-864

*Speaker

Modeling and identification of mechanical systems

A benchmark study on the configuration of metaporoelastic interfaces for acoustic isolation enhancement.

Thomas Weisser * [1], Jean Philippe Groby [2], Olivier Dazel [2], Logan Schwan [2], Elke Deckers [3], Alan Geslain [4], Clément Lagarrigue [5], Damien Lecoq [5]

[1] IRIMAS (EA7499) – Ecole Nationale Supérieure d'Ingénieur Sud Alsace, Université de Haute Alsace - Mulhouse, IRIMAS-UHA – France
[2] Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université – France
[3] Department of Mechanical Engineering, KU Leuven – Department of Mechanical Engineering, division PMA, KU Leuven, 3000 Leuven, Belgium., Belgium
[4] Département de Recherche en Ingéniérie des Véhicules pour l'Environnement (DRIVE) – Université de Bourgogne : EA1859 – 49 rue Mademoiselle Bourgeois, 58027 NEVERS, France, France
[5] Metacoustic – Metacoustic – France

Porous materials such as foams are commonly used to improve acoustic isolation due to their high viscothermal loss properties. However, they suffer from a lack of absorption at low frequencies compared to their efficiency at higher ones. While multi-layering approaches allow reducing the impedance mismatch at the air-material interface, they rapidly have to face size issues as their performance relies on the allowable thickness. Hence, metaporous surfaces/interfaces have been proposed by incorporating periodic resonant elements inside the porous layer to trap the sound energy inside the system at lower frequencies and to modify its attenuation properties [1]. In particular, split rings and Helmholtz resonators have proved to achieve perfect and/or wide band absorption under specific conditions [2]. More recent works have focused on the inertial regime of the porous material by accounting for the relative motion of its skeleton and embedding purely elastic inclusions [3], whose resonances may occur at lower frequencies than acoustic ones.
This paper proposes a benchmark study to investigate the acoustic isolation properties of a poroelastic layer, possibly coated by thin elastic plates, in both reflection and transmission problems. Different types of inclusions are considered, namely: rigid or full poroelastic ones, elastic thin shells filled with air, poroelastic/steel spring-mass resonators. A parametric study is performed to derive the influence of the associated design parameters on the acoustic isolation properties and to provide general design trends. Furthermore, these different configurations are used as test cases to compare a dedicated semi-analytical approach to an in-house code based on finite elements [4], thus cross-validating both methods and underlining some benefits and limitations.

J.-P. Groby, O. Dazel, A. Duclos, L. Boeckx, and L. Kelders, "Enhancing the absorption coefficient of a backed rigid frame porous layer by embedding circular periodic inclusions", J. Acoust.

*Speaker

Soc. Am., 130, 3771–3780 (2011).

J.-P. Groby, C. Lagarrigue, B. Brouard, O. Dazel, V. Tournat, and B. Nennig, ”Enhancing the absorption properties of acoustic porous plates by periodically embedding Helmholtz resonators”, J. Acoust. Soc. Am., 137(1), 273–280 (2015).

T. Weisser, J.-P. Groby, O. Dazel, F. Gaultier, E. Deckers, S. Futatsugi and L. Monteiro, ”Acoustic behavior of a rigidly backed poroelastic layer with periodic resonant inclusions by a multiple scattering approach”, J. Acoust. Soc. Am. 139(2), 617–629 (2016).

M. Gaborit, L. Schwan, O. Dazel, J.-P. Groby, T. Weisser and P. Göransson, ”Coupling FEM, Bloch waves and TMM in meta poroelastic plates”, Acta Acust *united* Ac., 104, 220-227 (2018).

The Dynamics of Helicopters with Nonlinearities on the Fuselage

Leonardo Sanches * [1], Cesar Augusto Borges Da Silva [2], Guilhem Michon [3]

[1] Université de Toulouse – ICA, CRNS, ISAE-SUPAERO, Toulouse – France
[2] Federal University of Uberlândia, School of Mechanical Engineering, Uberlandia - MG, Brazil – Brazil
[3] Université de Toulouse – ICA, CNRS, ISAE-Supaero, Toulouse, France – France

Concerning the helicopter dynamics, one aims to avoid the increment of vibrations in every possible operating conditions. Despite the dynamical characteristics of the mechanical components, the interaction of the helicopter with the terrain during starts and landings can cause multiples resonances which might lead to ground resonance with fatal consequences. Depending on the soil characteristics, the interactions with the terrain might lead up to nonlinear behaviours.
Moreover, in order to suppress the ground resonance, elastomeric dampers can play a significant role in the stability of the aircraft. Therefore, the modeling of the elastomeric lag dampers have received increasing attention, specially concerning its nonlinear characteristics. For example, Gandhi and Chopra place an additional nonlinear spring in series with the linear, parallel spring and dashpot in order to represent the elastomeric dampers.

Nevertheless, it is known from the literature that rotating machines under nonlinear operating characteristics could attain other than the periodic motion, predicted for linear systems, the quasi-periodic or chaotic motions.

Recently, Varney and Green observed the presence of quasi-periodic and chaos on the rotor dynamics by assuming rotor-stator contact. Indeed this phenomenon is observed since precisely manufactured bearings are used and thus reduced clearances are imposed for improving the performance of the rotating machines.
Under the hypothesis of nonlinearities presented on the ground resonance modelling, this paper aims verifying, if at certain operating conditions or design properties, the appearance of chaotic motion is reached. The helicopter considered contains nonlinear spring stiffness on the fuselage displacements (longitudinal and lateral). The four-bladed rotor consider rigid structures having only lead-lag oscillations. Parametric analyses combined with examination of the Poincare maps and bifurcation diagrams, the nonlinear dynamical behavior of the helicopter was assessed. Non-periodic motion is attained for several rotor speed values and helicopter configuration analyzed.

*Speaker

Comparison of pseudo-static and modal spectral seismic analyses of motor-driven pump units: is 1.5 security coefficient of pseudo-static method relevant?

Sylvie Audebert * [1,2], Damien Rousseu [3]

[1] Institut des Sciences de la mécanique et Applications industrielles – Commissariat à l'énergie atomique et aux énergies alternatives, École Nationale Supérieure de Techniques Avancées, Centre National de la Recherche Scientifique : UMR9219, Université Paris-Saclay, EDF : RD – France
[2] EDF Recherche et Développement – Electricité de France - EDF – France
[3] EDF Direction Technique – Electricité de France - EDF – France

In the framework of the seismic verification of plant equipments, the determination of the seismic loads applied to motor-driven pump anchorages is optimised. A rough justification is usually first performed using the 1 degree-of-freedom pseudo-static analysis, including a 1.5 multi-mode factor. The question is asked about the opportunity to decrease the multi-mode factor value, by comparison to response spectrum analysis, here considered as the reference method. Comparative seismic analyses are performed on more and more complex dynamical systems and excitations; seismic responses of a thin square plate, motor, pump, motor-driven pump unit, connected or not to suction and delivery pipes, are thus successively determined, under 1D and 3D excitations. Two different motor-driven pump units are studied: flexible with vertical axis and stiff with horizontal axis. The quantities of interest are the shearing and tearing loads, deduced from seismic loads at anchorage points.

*Speaker

Characterization of the damping added by a foam on a plate by an inverse vibration problem

Meryem Le Deunf * [1,2], Charles Pézerat [2], Frédéric Ablitzer [2], Serge Puvilland [1]

[1] CEVAA – CEVAA – France
[2] Laboratoire dácoustique de lúniversité du Mans – Le Mans Université, Centre National de la Recherche Scientifique : UMR6613 – France

The industrial solution used today to improve the acoustic performance of a structure is often ensured by the addition of damping treatments such as elastomer, PVC or bituminous. In the transportation, these materials increase the costs and mass of the vehicle and have a negative environmental impact. Unlike theses heavy materials, it is commonly known in the professional standards of automotive designers that foams in vehicle trim provide damping to the structure. It has been shown that some impregnated PU foam coatings provide significant and equivalent damping to conventional bituminous materials used in the automotive industry. This observation makes it possible to extend the function of the trim to vibration damping, in order to mutualize the both problem (acoustic and vibration) in one treatment. To understand and quantify this dissipation mechanism involved by adding a porous material to a supporting structure [1], it is proposed to treat the problem from the angle of an experimental quantification obtained by an inverse problem. The proposed approach is based on the use of the Force Analysis Technique (FAT) method [2-3], where the first objective is to locate and quantify the forces applied to a vibrating structure. In this case, the FAT is designed to define the damping provided by the foam to the vehicle trim [4-5].
Keywords : foam, damping, FAT method

References:

Z. Abbadi, N. Merlette, N. Roy, Response Computation of Structures with Viscoelastic Damping Materials using a Modal Approach - Description of the Method and Application on a Car Door Model Treated with High Damping Foam, 5th Symposium of Automobile and Railroad Comfort, Le Mans, France, Nov. 19-20, 2008.

C. Faure, Identification de source vibratoire sur structure mal connue – Thèse Sci. - Université du Maine, 2016.

T. Wassereau, Caractérisation de matériaux composites par problème inverse vibratoire – Thèse Sci - Université du Maine, 2016.

*Speaker

F. Ablitzer, C. Pezerat, J.-M. Genevaux, J. Begue, , Identification of stiffness and damping properties of plates by using the local equation of motion, Journal of Sound and Vibration, Volume 333, Issue 9, 2454–2468 p, 2014

Q. Leclere, F. Ablitzer, C. Pezerat, Practical implementation of the Corrected Force Analysis Technique to identify the structural parameter and load distributions, Journal of Sound and Vibration, Volume 351, Issue 1, 106-118 p, 2015.

Numerical simulation for finding the free surface of liquid in an open container with horizontal acceleration

Reza Babajanivalashedi * [1], Jean-Luc Dion [1], Stefania Lo Feudo [1]

[1] Laboratoire QUARTZ EA 7393 - SUPMECA Paris – Laboratoire QUARTZ EA 7393 - SUPMECA Paris, 3 rue Fernand Hainaut, 93400 Saint Ouen, France – France

Liquid sloshing is a crucial problem for the dynamic of moving containers. This problem which is also known as Faraday waves was subjected to the many problems of sloshing with different movements and different shapes of containers. Sloshing problems have been modeled mainly with fluid dynamics and equivalent mechanical parameter models and also with experimental analysis. The purpose of this research is to simulate the free surface of the liquid with mode shapes. The first step of this work is to find a simple linear design model based on Navier-Stokes equations. To this purpose, Irrotational movement of flow, and inviscid were assumed for the liquid. Displacement equation was determined with the separation variable to find the space variable of mode shape. Then, a laboratory experiment of liquid sloshing with the horizontal movement carried out to find the movement of the free surface of the liquid. This experiment was held by using high-speed cameras. Hence, the shapes of the free surface of the liquid, which were carried out with cameras, were simulated by using mode shapes.

*Speaker

Coupled bending torsional vibrations of non-ideal energy source rotors going through critical speeds

Emna Sghaier * [1,2], Jean-Luc Dion [1], Nicolas Peyret [1], Didier Remond [2], Adeline Boudon [2]

[1] SUPMECA - Institut supérieur de mécanique de Paris – Laboratoire QUARTZ EA 7393 - SUPMECA Paris, 3 rue Fernand Hainaut, 93400 Saint Ouen, France – France
[2] LaMCoS – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France. – France

With the increasing number of rotors working at very high angular velocity, it becomes crucial to understand the dynamic behavior of rotating machineries when going through critical speeds. Models assuming constant velocity speed are not valid in this case of study since crossing the critical speeds implies necessarily non-stationary working conditions. The present work offers a new finite element model for rotors working at non-stationary regime. The rotational speed is introduced to the unknowns of the dynamic problem and six degrees of freedom are considered on each node. A main focus is given to the study of the coupling between the torsional and flexural degrees of freedom. This coupling is introduced by the intrinsic gyroscopic effect as well as the mass unbalance terms. It results in torsional vibrations containing frequency components of twice the excitation frequency of the mass unbalance as well as frequency components reflecting a modulation with the first bending natural frequency. We show that when crossing the critical speed, an additional frequency component of four times the lateral excitaion frequency appears. The coupling is observed through the analytical equations of motion and confirmed by the numerical simulation.

*Speaker

NAFID - A Grid Tool for output only modal analysis

Viet-Hung Vu * [1]

[1] ecole de technologie superieure – Canada

In this paper, we propose a technique to enhance and facilitate the output only modal analysis of systems and structures by using the vector autoregressive (VAR) model. As we have witnessed, the VAR model with its robustness, accuracy and noise - excitation resistance is beneficial for output only modal analysis. However, the VAR model and others parameters models have to deal with the variation of the model orders such as the frequency stabilization diagram. A grid technique is introduced to classify the natural frequencies and damping ratios in order to automatically evaluate its stabilization. The combination of the grid technique and the stabilization diagram will allow to users to have a better perspective of the modal parameters and a more accurate modes. The method is implemented and built in Matlab as the NAFID-tool which is users friendly and interactive. Examples on simulations of a MDOF system and on a real structure the applicability of the technique.

*Speaker

Study of the static and dynamic behaviour of PU foam: from the material sample to the automotive seat.

Corentin Blanchard * [1,2], Thomas Weisser [1], Romain Barbeau [2], Evelyne Aubry [1], Anne-Isabelle Mallet-Da Costa [2]

[1] Institut de Recherche en Informatique, Mathématiques, Automatique et Signal – Université de Haute Alsace - Mulhouse : EA7499 – France
[2] FAURECIA Sièges Automobile S.A. – FAURECIA – France

The transformation of the automotive industry leads seat manufacturers to consider new seating postures in the cockpit. For each of them, vibrational comfort is part of the desired performances. It is commonly defined by the transmissibility, expressed as the ratio between the acceleration at the seat surface and the one at its base [1], thus characterizing the vibration filtration of the seat. It is obtained when the seat is loaded by a rigid mass, a manikin or a human subject.
The present paper concerns the development of a finite element (FE) model of a seat and an occupant in order to compute the transmissibility of the seat. The whole forms a complex system due to the number of sub-components at stake, but previous studies showed that the foam pads have a significant influence on the mechanical behaviour of the seat [2]. Therefore, a simplified FE model has been developped using a foam sample and a rigid mass that act as the seat foam pad and the occupant.

The foam behaviour is viscoelastic, non-linear and depends on the applied prestress [3]. In the present case, the prestress comes from the sinking of the rigid mass on the foam sample due to the gravity. This also leads to a change of the model geometry. It is therefore mandatory to perform a static analysis before computing the transmissibility around this operating point.

The static analysis is realized by applying the gravitational acceleration to the FE model until it reaches an equilibrium state. Once it is obtained, the new model geometry as well as the internal prestresses within the elements are extracted and used as input data for the dynamic analysis, during which the transmissibility is computed [4].

This methodology is validated using available data coming from compression tests as well as dynamic tests using a free mass. It also allows to study the influence of the different model parameters on the outputs of the static and dynamic analyses. Finally, it will be applied to an industrial case study by simulating the seating phase of an occupant on a seat and by computing the associated transmissibility.

ISO standard (2001). ISO-5982. Mechanical vibration and shock - Range of idealized values

*Speaker

to characterize seated body biodynamic response under vertical vibration. ISO-5982. Geneva. International Standard Organization.

Barbeau, R. (2018). Characterization and modeling of automotive seat dynamics: toward the robust optimization of vibrational comfort. PhD Thesis. Université de Haute-Alsace, France.

Hilyard, N. C., & Cunningham, A. (1994). Low density cellular plastics, Chapter 8 - Hysteresis and energy loss in flexible polyurethane foams. Springer-Science, B.V., 226-269.

LSTC (2014). LS-DYNA Keyword User's Manual, Volume I. Livermore. Livermore Software Technology Corporation.

Condition Monitoring

Edge computing for advanced vibration signal processing

Jan Helsen * , Peeters Cédric [1], Patrick Guillaume

[1] Vrije Universiteit [Brussel] (VUB) – Pleinlaan 2, 1050 Brussels, Belgium

Today, Industry 4.0 is being introduced. Machines are equipped with internet connection and increasingly sensorized using Industrial Internet of Things (IIoT) sensors. Especially the emergence of 5G is a game changer in this regard. It becomes possible to send data at high speeds to cloud computing data-centers. However, streaming all data is deemed to be unfeasible. It is more advantageous to use the additionally available bandwidth to drastically increase the number of connected sensors. Thus, on-board processing of the data directly at the edge is necessary.
This paper illustrates this edge computing concept using data of wind turbines. The spectral coherence approach is one of the most promising approaches for bearing fault diagnostics to extract the most optimal envelope. This approach requires a significant amount of computational power. Today, different Advanced Risc Machine (ARM) processors are available in embedded architectures. Moreover, CPU based single board computers are available. The edge computing concept is validated by processing a vibration processing pipeline containing this spectral coherence method using such architectures. Both healthy and faulty data sets are processed. Performance benchmarking is done compared to a traditional computer. Adaptations are done to the spectral coherence method to make it more suitable for the embedded architecture.

*Speaker

Remote diagnosis by analyzing heterogeneous data

Joris Guerry , François Chanel * [1], Nicolas Tardieu

[1] EDF RD – EDF Recherche et Développement – France

In the 2000s, EDF's hydropower sector launched a project to modernise its Information System, including national harmonisation of nomenclatures. This new indexing, ranging from the regional scale to the details of the sensors installed on our equipment, now makes it possible to create a tool for handling all raw data previously unimaginable on the scale of the national hydraulic fleet.
The various databases supplied (production time data, current and exceptional maintenance reports, operational contingencies, etc.) remain however always stored on different media, not designed to interact together.

EDF R&D has therefore produced a tool for the joint cross-referencing and display of heterogeneous data in order to demonstrate the additional added value that can be derived from the concomitant use of data of different kinds. This new tool primarily targets 2 types of data:

- Hydropower plant process data, i.e. time series from the sensor fleet present at each production site.
- Maintenance data, essentially containing text data from structured forms containing irregularly filled in free fields.

In practice, the tool allows, on the one hand, to display several time series of sensors between two dates, and on the other hand, to superimpose on the same graph the relevant maintenance acts, linked to the displayed sensors. We then use the efficient structuring of sensor nomenclatures and maintenance data to sort by relevance the maintenance events to be displayed first, based on expert knowledge

The main actor benefiting from this tool is the e-monitoring of the hydraulic fleet. The engineers of the regional e-monitoring centres remotely supervise the monitoring of a whole fleet of machines in order to detect slow drifts or the crossing of alert thresholds. On the contrary, the operational units manage the maintenance operations directly from site. This decoupling leads to a phase shift between the e-monitoring cells, which do not have a perfect knowledge in real time of the work performed, whereas these works, by affecting the behaviour of the machines, generate many alerts or events wrongly interpreted as suspicious. This situation generates numerous telephone exchanges between maintenance and e-monitoring teams in order to explain

*Speaker

the changes in trend induced by maintenance operations.
The tool developed aims to reduce the number of exchanges by making e-monitoring cells more autonomous in interpreting abnormal behaviour detected by direct access to contextual information of primary importance: maintenance operations carried out on sites. E-monitoring teams will also be able to build statistical indicators related to maintenance (time before new failure following repair, warning signals before failure, etc.) using historical data.

TOOL CONDITION MONITORING METHOD IN MILLING PROCESS USING WAVELET TRANSFORM AND LONG SHORT-TERM MEMORY

Fatemeh Aghazadeh * [1], Souheil-Antoine Tahan [2], Marc Thomas [3]

[1] ecole de technologie superieure – Canada
[2] Ecole de Technologie Supérieure (ETS) – 1100, rue Notre-Dame Ouest Montréal (Qc) H3C 1K3 Canada, Canada
[3] École de technologie Superieure (ETS) – 1100 Notre Dame West, Montréal, H3C1K3, Québec,, Canada

Industrial automation is a promising move to fulfill today's competitive manufacturing industry demands by lowering operation costs, increasing productivity and quality. Monitoring the production process is one of the important steps toward total autonomy of manufacturing plants, which reduces routine checks, enables proactive maintenance and reduces repair costs. This research investigates tool wear as one of the most common faults in milling process during cutting of the D2 high speed steel as a hard to cut material using Carbide Walter End Mill Protostar tool. Vibration signal is chosen to represent the system status due to its applicability in industry. Signals are transformed into time-frequency domain using Wavelet Transform method to reveal both time domain and frequency domain features of the signal simultaneously. In order to model the complex and non-linear relations between tool wear and vibration signals under varying cutting parameters, a deep learning based algorithm, Long Short-Term Memory (LSTM) Artificial neural networks (ANNs) is employed. Deep learning algorithms are getting lots of attention recently within the diagnosis and prognosis community because of their exceptional performance in exploiting information in big data to solve complex problems. LSTM network is a type of recurrent ANNs that have some internal cells that act as long-term or short-term memory units, which is most suitable for sequential data and time series like vibration signals in our analysis. After designing the system, performance of the monitoring method is validated using experimentally acquired data with K2X10 Huron high speed CNC machine in LIPPS and Dynamo labs of ETS.
Keywords Deep Learning, Tool Wear, Wavelet Transform, Condition Monitoring, Time-Frequency Transformation, Machining Process

*Speaker

Signal processing

Selection of Condition Indicators for Improved Gear Fault Detection

Eric Bechhoefer * [1]

[1] GPMS Inc – United States

Abstract: This study focuses on improving gear fault detection through improved the selection of condition indicators (CIs) used in component health determination. Given a set of CIs, a gear health indicator is built which is a function of the CI distributions. The health index value is then a composite of the CIs and represents a threshold setting process. In practice the CI used for gear fault detection were: residual kurtosis, residual crest factor, energy operator kurtosis, Figure of Merit 0, Amplitude Modulation Kurtosis and Frequency Modulation RMS. While no single CI can detect all gear failure modes, through testing, it was found that these analyses were sensitive to a wide variety of damage, such a soft tooth, cracked tooth and scuffing.
Residual RMS : 10.4913

NB Kurt : 8.1316

NB CF : 7.6465

G2 : 6.6145

Residual CF : 6.1483

Residual Kurt: 5.4878

SMLF : 5.0228

FM Kurt : 4.3065

FM RMS : 4.3028

AM RMS : 3.7933

AM Kurt : 2.3861

FM0 : 2.0513

Energy Kurt : 1.5531

Energy CF : 1.3219

*Speaker

Gear Mesh : 0.8424

Energy Ratio : -0.33925

Recently, a deployed system recorded a large data set from three nominal gearboxes (approximately 100 acquisitions each), and a gearbox with a cracked tooth (270 acquisitions). This is a statically large data set which allows determining the statically separability between the nominal and damage gear CIs. This test was done for sixteen condition indicators. The results of the testing are given:

Clearly, the testing suggested a different mix of CI could improve the performance, as some analysis did not perform as well as other. The selection of the new set of CI is explained, as consideration for specificity (the residual and energy operator are not shaft specific, while G2, SL, NB, FM and AM analysis are specific to a gear), and the desire to provide limit risk using different types of analysis are taken. The new set of CIs were: Residual RMS, Energy Operator Kurtosis, Sideband Lifting, Narrowband Kurtosis, AM RMS and FM RMS.

Subsequently, data was taken for a two stage, bevel gearbox that had a propagating gear fault. This allowed the comparison in the gear health index between the new and old set of CI. Using the new CI set, the gear health index was approximately 3x more sensitive to gear fault.

Ref:

Bechhoefer, E., He, D., Dempsey, P, "Gear Health Threshold Setting Based On a Probability of False Alarm" Annual Conference of the Prognostics and Health Management Society, 2011.

Stewart, R., M., "Some Useful Data Analysis Techniques for Gearbox Diagnostics', Proc. of Meeting on Applications of Time Series Analysis, 1977

McFadden, P.D. Detecting Fatigue Cracks in Gears by Amplitude and Phase Demodulation of the Meshing Vibration, Journal of Vibration, Acoustics, Stress and Reliability in Design, 1986.

Ma., J., Energy Operator and Other Demodulation Approaches to Gear Defect Detection, MFPT 49 Proceedings, 1995.

Autonomous Embedded Vibroacoustic Measurements: an efficient tool for railway monitoring

Christian Clerc * [1], Romain Augez *

2

[1] Vibratec (Vibratec) – vibratec – 28 Chemin Petit Bois - BP 36 - 69131 Ecully Cedex, France
[2] VIBRATEC – Vibratec, vibratec – France

Efficient maintenance and monitoring are key points for rolling stocks or railways networks operators. A good knowledge of the structural health and a capability to predict its evolution are main assets to insure a high level of performance. Vibrations and dynamic forces borne by the wheel rail contact contain the main information to reach this objective. Therefore mechanical health features can be deduced from the signal measured on the bogie or on the rail using appropriate data processing algorithms. Moreover the improvements in electronics or communication technologies allow to integrate measurement and data processing functions in an embedded compact system.
The Vibratec wheel rail contact experience leads to consider a cross indirect measurement: a sensor mounted on bogie to monitor the rail and a sensor mounted on rail to monitor the vehicle. Upon this assumption, Vibratec develops a new tool able to detect the defaults and to assess their evolution. To reach the objectives the device must be able to measure vibrations, acoustics, train speed and location, then to process and send the data. A key point is to perform dedicated algorithms to identify and quantify defaults from different origins operating in time domain or in frequency domain.

This paper presents the tests performed with a prototype which includes microphone, accelerometers, magnetic speed sensor and GPS positioning system. The presented results are deduced from measurements carried out on a tramway bogie running on the urban network. The analyse is focused on the rail corrugation, quantified by its roughness and its wavelength. The comparison to the measurements delivered by a corrugation analysis trolley highlight the efficiency of the prototype.

*Speaker

Blind vibration filtering using envelope spectrum indicators for bearing and gear fault detection without knowledge of machine kinematics

Peeters Cédric * [1], Jérôme Antoni [2], Jan Helsen [3]

[1] Vrije Universiteit [Brussel] (VUB) – Pleinlaan 2, 1050 Brussels, Belgium
[2] Laboratoire Vibrations Acoustique (LVA) – Institut National des Sciences Appliquées de Lyon – Bâtiment St. Exupéry, INSA Lyon, 25 bis, avenue Jean Capelle 69621 VILLEURBANNE CEDEX, France
[3] Vrije Universiteit Brussel – Belgium

Abstract

The central idea behind this paper is to propose a means to filter out vibration signals of interest from a fault detection perspective without actually having knowledge about the kinematics of the machine. In other words, this paper investigates blind deconvolution filters that do not require a-priori knowledge about the fault frequencies, e.g. of a bearing or gear. This kind of approach opens the door for the condition monitoring of complex machines where insufficient information is available about the inner components or where replacements have been carried out that changed characteristic frequencies and that were not logged. In recent years there has been a fair amount of renewed interest in fault detection using blind separation or deconvolution techniques [1, 2, 3].

Many look at the time-domain vibration signal itself to maximize a certain indicator on. Examples include maximization of the Jarque–Bera statistic [1] of the time waveform to detect deviation from a normal distribution and the lp/lq-norm [2] to maximize the sparsity of the signal. Recently the degree of second-order cyclostationarity (CS2), a familiar quantity in the mechanical signal processing community, has been used as an objective to be maximized [3]. While maximizing the cyclostationarity of a signal directly influences the envelope spectrum of a signal (since it will try to maximize the peak at the desired cyclic frequency), it still requires a-priori knowledge of the characteristic frequency of interest. This paper however proposes to employ the envelope spectrum directly as a metric for the blind filter. The main assumption of the proposed method is that when a fault occurs, it introduces a CS2 component in the vibration and thus this component shows up in the (squared) envelope spectrum (SES) as a discrete peak at its corresponding fault frequency. This discrete peak correspondingly also increases the sparsity of the SES. To avoid interfering influences of CS1 components, the signal has to be pre-whitened, e.g. through linear prediction filtering, cepstrum editing, etc. This is essential because these interfering components produce high-amplitude discrete peaks in the envelope spectrum skewing the sparsity of the SES. The paper investigates the maximization of the L2/L1-norm, a common measure of sparsity, of the SES for use in the iterative updating procedure of the blind filter.

*Speaker

Keywords
Blind deconvolution, vibrations, sparsity, envelope spectrum, L2=L1-norm, fault detection

References

Obuchowski J, Wylomanska A and Zimroz R 2016 New criteria for adaptive blind deconvolution of vibration
signals from planetary gearbox Advances in Condition Monitoring of Machinery in Non-Stationary Operations (Springer) pp 111–125

Jia X, Zhao M, Buzza M, Di Y and Lee J 2017 Signal Processing 134 63–69

Buzzoni M, Antoni J and D'Elia G 2018 Journal of Sound and Vibration 432 569–601

Vibration representation in time and phase domains, applications to aircraft engines

Julien Griffaton * [1], Jose Gomez

[1] Safran Aircraft Engines – Safran Aircraft Engines – France

While in operation, aircraft engines may be subjected to various severe mechanical events such as bird ingestion, blade separation, ice accretion, shaft unbalance, compressor stall or rotor-stator interaction. During the development of a new engine application, such phenomena are simulated in test cells in order to make sure that the engine will still operate safely. During such tests, accelerometers and strain gages are mounted on the engine cases and near the shaft bearings in order to measure loads and vibrations and in order to understand the engine behaviour. The engine dynamic behaviour during those phenomena may be fleeting or sustained, cyclic or asynchronous, transient or stationary. Usual analysis are performed in various domains such as time, frequencies and orders of a rotating shaft speed, depending on the nature of the vibration behaviour. This paper describes a new kind of vibrations representation that considerably facilitate the interpretation of fleeting or sustained events when both time and phase location of a shaft are meaningful. In a first section of the paper, the representation is described with a simple lumped-mass model of a rotating shaft operating with variable angular speed. In a second section, the representation is applied on a real aircraft engine during tests with various engine behaviours. The last section presents a simulation of those different behaviours with a simple model.

*Speaker

Fault diagnosis and prognosis for rolling bearings

Fourier-Bessel series expansion based blind deconvolution method for bearing fault detection

Elia Soave * [1], D'elia Gianluca [2], Dalpiaz Giorgio [2]

[1] Department of Engineering, University of Ferrara (ENDIF-UNIFE) – Italy
[2] Department of Engineering, University of Ferrara – Italy

In the last few years blind deconvolution techniques proved to be useful in order to extract impulsive patterns related to bearing fault from noisy vibrational signals.
Recently, a novel blind deconvolution method based on the generalized Rayleigh quotient has been proposed and an iterative algorithm related to the maximization of the cyclostationarity of the source has been defined.
This paper presents a new condition indicator that exploits the Fourier-Bessel series expansion for the computation of a new cyclostationarity index that drives the maximization problem for the extraction of the excitation source.
This work compares the proposed indicator with the classical one, based on the Fourier transform, in term of computation efficiency.
The comparison between the application of the two different methods involves both simulated and real signal taking into account a bearing fault.
The results prove the capability of the new indicator to extract the impulsive source without the need of a complete set of cyclic frequencies but only with the fundamental one, with a strong reduction of the computational time.

*Speaker

Combination of vibration analysis and Acoustic Emission measurements to better characterize damage and mechanical behaviour of aerospace high speed rolling bearing

Hebrard Yoann * [1]

[1] Engineer (SKF) – SKF-AEROSPACE, SKF – 29 CHEMIN de THABOR 26000 VALENCE, France

Designed to break the paradigm for efficiency, the new generation of engines promises double-digit reductions in fuel burn, as well as an unparalleled single-leap improvement in emissions and lower noise to fulfil societal environmental objectives for a more sustainable future. The end-use consumer and environmental policy requirements for aircrafts of the next generation translate into components with higher temperature and speed. Furthermore, new monitoring technics are needed to closely monitor rolling contact during testing of the next generation of aero engine bearing to check its behavior under the new application condition. Vibration analysis for condition assessment and fault diagnostics is widely used nevertheless interpretation and correlation of collected data is often cumbersome.
That is why combination of vibration analysis and acoustic emission techniques giving different types information in different frequency band can help to understand the behavior of new rolling bearing. This paper presents an experimental testing campaign on bearings with seeded defects. Correlation between low and high frequency signals with different strategy of signal acquisition are presented from signal processing step.

Real time transient analysis with feature extraction was done in parallel with streaming acquisition on both signals. Pattern recognition of individual AE signal is possible and were correlated with more traditional analysis based on signal enveloping vibration analysis. Continuous monitoring on finished duration were done to provide information on no stationary regime and also time of stabilization. Comparison between features extraction is done on damaged and defect free rolling bearing at several rotating speed and loading level.

Keywords : high speed rolling bearing, experimental data, condition monitoring, vibration analysis, acoutic emission

References:

Raad. A. Sidahmed, B; Early detection of the gear fault – advantage of the acoustic emission technique 25th European conference, Acoustic emission testing; EWGAE; 2002; Prague; 2;

*Speaker

II/125-II/130

Lekou, D.J., Mouzakis, F., Anastasopoulos, A. A., Kourousis, D., Fused Acoustic Emission and Vibration Techniques for Health Monitoring of Wind Turbine Gearboxes and Bearings; Scientific Proceedings of EWEC 2009, pp. 78-82., At Marseille

Boinet, M. Proust, A., Lenain, J.C., Yantio Njankeu Sabeya, G.R., Paris, J.-Y., Denape, J., Analyse par Emission Acoustique de la dégradation d'un contact sollicité en fretting, Journées Francophone de Tribologie Poitiers, 22–23 mai 2007.

Mathews, J. R. *Acoustic emission*, Gordon and Breach Science Publishers Inc., New York. 1983, ISSN 0730-7152.

Roger, L. M., The application of vibration analysis and acoustic emission source location to on-line condition monitoring of anti-friction bearings. *Tribology International*, 1979; 51-59.

Mba, D., Bannister, R.H., and Findlay, G.E. Condition monitoring of low-speed rotating machinery using stress waves: Part's I and II. Proceedings of the Instn Mech Engr 1999; 213(E): 153-185

N. Jamaludin, Dr. D. Mba, Dr. R. H. Bannister Condition monitoring of slow-speed

rolling element bearings using stress waves. Journal of Process Mechanical Engineering, I Mech E. Pro. Inst. Mech Eng., 2001, 215(E):, Issue E4, 245-271.

Yoshioka T, Fujiwara T. New acoustic emission source locating system for the study of rolling contact fatigue, *Wear*, 81(1), 183-186.

Yoshioka T, Fujiwara T. Application of acoustic emission technique to detection of rolling bearing failure, *American Society of Mechanical Engineers*, Production Engineering Division publication PED, 1984, 14, 55-76.

Hawman, M. W., Galinaitis, W. S, Acoustic Emission monitoring of rolling element bearings, *Proceedings of the IEEE, Ultrasonics symposium*, 1988, 885-889

Holroyd, T.J. and Randall, N., (1993), Use of Acoustic Emission for Machine Condition Monitoring, *British Journal of Non-Destructive Testing*, 1993, 35(2), 75-78.

Holroyd, T. Condition monitoring of very slowly rotating machinery using AE techniques. *14th International congress on Condition monitoring and Diagnostic engineering management (COMADEM'2001),* Manchester, UK, 4-6 September 2001, 29, ISBN 0080440363

Bagnoli, S., Capitani, R. and Citti, P. Comparison of accelerometer and acoustic emission signals as diagnostic tools in assessing bearing. *Proceedings of 2nd International Conference on Condition Monitoring*, London, UK, May 1988, 117-125.

Morhain, A, Mba, D, Bearing defect diagnosis and acoustic emission Journal of Engineering Tribology, I Mech E, Vol 217, No. 4, Part J, p 257-272, 2003. ISSN 1350-6501.

Levalllois, F., Sobeczko, A., Proust, A., Marlot, D., Lenain J.C. Non-destructive testing of GAIA frame by means of acoustic emission monitoring during launch simulation tests., 30th European Conference on Acoustic Emission Testing & 7th International Conference on Acoustic Emission University of Granada, 12-15 September 2012.

Neuroevolution for bearing diagnosis

Rita Sleiman [1], Amani Raad * [1], Souhayb Kass [3,2], Jérôme Antoni [4]

[1] Faculty of Engineering I, Lebanese University, Lebanon – Lebanon
[3] Doctoral School of Science and Technology, Lebanese University, Tripoli, Lebanon – Lebanon
[2] Laboratoire Vibrations Acoustique, Univ Lyon, INSA-Lyon, LVA EA677, F-69621 Villeurbanne, France – INSA Lyon – France
[4] Institut national des sciences appliquées de Lyon (INSA Lyon) – INSA Lyon – 20 Avenue Albert Einstein, 69621 Villeurbanne cedex, France

The monitoring of machinery and especially ubiquitous bearings in all means of transport has gained importance for decades in the industry because of the need to increase the reliability of machines and reduce the possible loss of production due to failures caused by the different faults. Many of the available techniques currently require a lot of expertise to apply them successfully. New techniques are required that allow relatively unqualified operators to make reliable decisions without knowing the mechanism of the system and analyzing the data. Reliability must be the most important criterion of the operation. Artificial intelligence is the revolutionary answer in all areas of industrial control. The main goal of this paper is to propose new solutions for bearing diagnosis based on deep neural networks (DNN). However, in general the optimization of the neural network architecture is done by trial and error, and the features reduction problem is solved by using the principal component analysis. In this paper, the application of the neuro-evolution is proposed for bearing diagnosis where the optimization of the neural network topology as well as the features reduction are done by an evolutionary genetic algorithm. An application of the general procedure is proposed for real signals; that shows the superiority of the combination between neural networks and genetic algorithms for bearing diagnosis.

References

- J.Ferner & M.Fischler, S.Zarubica & J.Stucki. (2017). Combining Neuro-Evolution of Augmenting Topologies with Convolutional Neural Networks.

- B.Samantha.(2004)Gear fault detection using artificial neural networks and support vector machines with genetic algorithms
Mechanical Systems and Signal Processing, Volume 18, Issue 3, p. 625-644.

*Speaker

Electrical motors

Long-term vibration monitoring of induction motors in the food industry with low-cost MEMS accelerometers

Agusmian Ompusunggu * [1], Karel Janssen , Vladimir Dzyuba

[1] Flanders Make – Belgium

Many production lines in the food industry, that run continuously 24 hours per day, are nowadays equipped with induction motors to drive machines to process raw materials to become final products. As the motor function in the production lines is vital, the motors failure can thus interrupt the production process that eventually leads to economic losses, i.e. higher production cost.
The statistical analysis on the maintenance record of a specific production line conducted in this study confirms that induction motor breakdowns are the major contributors of the unplanned production downtimes. Furthermore, this case study also shows that the common failure mode of the induction motors is due to the rolling element bearing faults, which is in line with the findings of many authors in the literature.
The main interest of the production line owner is how to minimise the unplanned downtimes such that the productivity is increased and the production cost is minimised. In this paper, we present a testimonial story of a setting-up a vibration monitoring system to continuously monitor the condition of motors for the first time in a real production line with MEMS-technology-based-low-cost accelerometers available on the market [1]. Some technical challenges and the state-of-the-art techniques used to compute health indicators from raw vibration signals are presented in this paper. The vibration monitoring system has successfully identified a damaged bearing in one of the monitored motors. This finding was also independently validated by a maintenance service company.

*Speaker

Structural dynamics of electric machines subjected to PWM excitations

Margaux Topenot * [1,2], Morvan Ouisse [3], Gaël Chevallier [4], Damien Vaillant [2]

[1] Département de Mécanique, FEMTO-ST – CNRS : UMR6174 – France
[2] Alstom - Ornans – Alstom transport – France
[3] UBFC/FEMTO-ST – Univ. Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST, CNRS – Département Mécanique Appliquée 24 chemin de l'Epitaphe 25000 Besançon, France
[4] UBFC/FEMTO-ST – Univ. Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST, CNRS – France

Pulse Width Modulation (PWM) is commonly used for driving asynchronous machines. The mechanical torque is the result of the combination of several multiphysics conversions. The PWM is generally defined on the basis of the electromagnetic performances determined with simple mechanical behavior: typically, rigid bodies are considered to be representative of the mechanical load. However, since PWM generates numerous harmonics of current and voltage, it may have an impact on the structural dynamics of the system. In particular, the rotor is subjected to torque oscillations over a wide frequency range that may result in large vibration amplitudes when coincidences occur. These excitations can induce severe damages like fans ruptures. In this work, a finite element model and an analytical model are compared in terms of ability to describe the structural dynamics of the system when the electric machine is driven with PWM. The results are compared and discussed in terms of applicability for the design of electric machines.

*Speaker

Experimental evidence of MCSA for the diagnosis of ball-bearings

Fabio Immovilli , Marco Lippi , Marco Cocconcelli * [1]

[1] Department of Science and Engineering Methods, University of Modena and Reggio Emilia (DISMI-UNIMORE) – Via G. Amendola, 2 - Pad. Morselli 42122, Reggio Emilia, Italy

Electrical and mechanical fault diagnosis in induction machines is an extensively investigated field for cost and maintenance savings, as induction motors operating at mains frequency are still the most widespread rotating electric machines in industry. Many papers can be found in the literature concerning the general condition monitoring of induction machines [1]. Bearing faults are one of the most common failures in electrical machines especially in the small-medium power sizes. Bearing faults that are not detected in time cause malfunction, loss of performance, reduced efficiency, and may even lead to failure of the driven machinery. Online fault detection can be obtained by vibration analysis [2], but the diagnosis equipment is costly and invasive, requiring dedicated equipment and specific sensors to be installed. Motor current signature analysis (MCSA) is an alternative method that relies on the monitoring of electrical quantities, that are already acquired in the final application, e.g., to implement the control of an electric drive, thus do not require the installation of dedicated transducers. Many research activities were focused on the diagnosis of bearing faults by MCSA [3]. The use of suitable signal processing techniques is required to efficiently extract the fault signatures from raw signals. The use of current and/or voltage signal constitutes a noninvasive method to bring information necessary to diagnose a fault in the system via online monitoring of the electric machine [4].
This paper details the results of a laboratory trial (Figure 1) comprising different test sets on the condition monitoring and fault diagnostic of a six-poles induction motor using a design of experiment (DOE) approach. The paper discusses the results of MCSA compared to vibrational data and the perspectives offered by long short-memory networks.

Keywords: MSCA, condition monitoring, ANOVA, long short-memory networks.

S. Nandi, H. A. Toliyat, and X. Li, "Condition monitoring and fault diagnosis of electrical motors-a review," IEEE Trans. Energy Convers., vol. 20, no. 4, pp. 719–729, Dec. 2005.

I. El-Thalji and E. Jantunen, "A summary of fault modelling and predictive health monitoring of rolling element bearings," Mechanical Systems and Signal Processing, vol. 60, pp. 252–272, 2015.

A. Ibrahim, M. E. Badaoui, F. Guillet, and W. Youssef, "Electrical signals analysis of an asynchronous motor for bearing fault detection," in Proc. 32nd Annu. Conf. IEEE Ind. Electron., Nov. 2006, pp. 4975–4980.

*Speaker

M. Blodt, P. Granjon, B. Raison, and G. Rostaing, "Models for bearing damage detection in induction motors using stator current monitoring," IEEE Trans. Ind. Electron., vol. 55, no. 4, pp. 1813–1822, Apr. 2008.

Multi-physics modeling of asynchronous electrical machines in non-stationary conditions with eccentric rotor

Xiaowen Li * [1,2], Adeline Bourdon [1], Didier Remond [3], Samuel Koechlin [2]

[1] Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France, Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France. – France
[2] Leroy Somer – EMERSON – France
[3] Laboratoire de Mécanique des Contacts et des Structures (LaMCoS) – CNRS : UMR5259, Institut National des Sciences Appliquées (INSA) - Lyon, Institut National des Sciences Appliquées [INSA] - Lyon – Bâtiment Jean d'Alembert 18-20, rue des Sciences F69621 VILLEURBANNE CEDEX, France

The large demands of electrical machines in various industrial fields has driven an intensified attention to their conception design and dynamic behavior analysis especially for NVH purposes in the automotive industry. One of the main reasons of the electrical machine vibration is the electromagnetic vibration caused by the uneven air-gap [9]. The air-gap eccentricity is often generated by the misaligned of the rotor rotation axis and the stator axis, which can be caused by either installation parallel deviation, bearing wear or mass unbalance. All these mechanical defects lead to the presence of the unbalanced magnetic pull (UMP) in the motors. This electromagnetic radial force drives the rotor to move along with the direction to the minimum of the air-gap and continues to worse the eccentricity problem. Meanwhile the variations of the parameters in magnetic field generate the new magnetic force to change the mechanic behavior of the motor. Therefore, a multi-physics modelling including the strong electromechanical coupling of the electrical machines is of great importance. In this paper, a multi-physics model combining the electromagnetic part based on Permeance Network Method and the mechanic part based on Timoshenko beam theory is proposed to describe both the mechanic and electromagnetic performance of the asynchronous cage induction motors. With a three-phase supply voltage as an input data, all the simulation results like the currents in the stator, the currents in the rotor and the displacement and velocity of each element of the rotor are obtained. The electromagnetic torque and the radial motor eccentric force are calculated by using virtual work method. Simulation results of the generated torque and stator's current are verified by comparing with some results offered by an integrated software on a realistic electrical machine from our industrial partner. Moreover, the influence of different values and configurations of dynamic and static eccentricities have been drawn and discussed in the analysis section of the paper. Some comparisons with existing references will also be presented in the same part. Also by applying an angular approach on this multi-physics description, this model is capable to simulate the dynamic behavior of the motor in non-stationary operating conditions in speed or load without any assumptions on the speed and the rotational degree of freedom of the rotor is preserved as a state variable. The motor's nonlinear dynamic behavior with the variation of the rotation speed are simulated and according to the simulation results, the influence of the varied rotor speed to

*Speaker

the whole system response is reported in this contribution.

Uncertainties, stochastic, robustness

Robust design of damping devices constitued of viscoelastic materials

Kévin Jaboviste * [1], Emeline Sadoulet-Reboul [1], Nicolas Peyret [2], Charles Arnould [3], Eric Collard [3], Gaël Chevallier [1]

[1] Franche-Comté Électronique Mécanique, Thermique et Optique - Sciences et Technologies (UMR 6174) – Université de Franche-Comté, Centre National de la Recherche Scientifique : UMR6174, Ecole Nationale Supérieure de Mécanique et des Microtechniques, Université de Technologie de Belfort-Montbeliard – France

[2] Laboratoire dÍngénierie des Systèmes Mécaniques et des MAtériaux – Université Paris 8 Vincennes-Saint-Denis : EA2336, SUPMECA - Institut supérieur de mécanique de Paris – France

[3] Thales LAS France – Thales (France) – France

The proposed work aims to provided tools the design of damping devices constitued of viscoelastic materials parts. A strategy is thus proposed to take into account the behavior of viscoelastic materials in different types of simulations: modal analysis, frequency response or temporal response. To achieve this goal, a generalized Maxwell model is introduced, and a dynamic model of the damper is written in an original form. To reduce the cost of calculation, this orignal formulation is associated with a model reduction strategy. Moreover, as the viscoelastic materials are very sensitive to temperature variations, this parameter is introduced in the generalized Maxwell model to investigate its influence on the modal damping. In this context, and using the developed methodologies, a robustness study is performed using the info-gap theory to evaluate the modal damping performances for two viscoelastic materials in an uncertain temperature environment. It is shown that the best design choice in terms of viscoelastic behavior really depends on the degree of lack-of-knowledge: robust and better performances can be obtained while quantifying the horizon of uncertainty

*Speaker

A model reduction method to analyze the dynamic behavior of vibrating structures with uncertain parameters

Duc-Thinh Kieu * [1], Marie-Laure Gobert [1], Sébastien Berger [1], Jean-Mathieu Mencik [1]

[1] Laboratoire de Mécanique Gabriel LaMé – Univ. Orléans, Univ. Tours, INSA CVL, Lamé, EA 7494, France – France

Assessing the dynamic response of vibrating structures which are described by means of finite element (FE) models with many degrees of freedom (DOFs) is usually computationally cumbersome. The fact that the manufacturing process and the material properties of structures are usually subject to variability means a dispersion of the physical parameters which can be important. The parameters are therefore considered as uncertain DOFs, which makes FE models more complex. The Monte Carlo (MC) method is commonly used to analyze the propagation of uncertainties through FE modeling. However, it requires a large number of simulations which are therefore very cumbersome in terms of CPU times.
This work aims at developing a low cost computational strategy to compute the harmonic response of vibrating structures having uncertain parameters. The strategy works by considering the Craig-Bampton method to reduce the physical DOFs of a FE model [1]. Also, a generalized Polynomial Chaos (gPC) expansion is considered to describe the propagation of uncertainties and estimate the Quantities of Interest (QoIs), e.g., the displacement at some measurement points, or an energy quantity. Intrusive and non-intrusive methods are both considered to apply the gPC expansion [2, 3]. In the first case, the Galerkin projection method is used to express the FE dynamic equilibrium equation of a structure in a gPC subspace; as for the non-intrusive method, it requires a non-negligible number of simulations of the FE model to be performed to estimate the gPC coefficients, and further the statistics (i.e., mean and variance) of the QoIs. The probability law of the QoIs can be obtained by considering the gPC expansions along with the MC method with 10,000 trials.

In this work, both the intrusive and non-intrusive methods are applied to model an academic structure made of two rectangular Kirchhoff-Love plates connected together across one of their edges by means of a lineic density of torsional springs with an uncertain stiffness. Comparisons with the results obtained from a reference MC solution involving 10,000 simulations of the FE model show good agreement and substantial reduction of the computational effort. The advantages and drawbacks of the intrusive and non-intrusive methods are discussed through numerical comparisons, as well as the influence of the Craig-Bampton reduction method on the estimation of the QoIs of the FE model.

R. R. Craig, M. C. C. Bampton, Coupling of substructures for dynamic analyses, *AIAA Journal*

*Speaker

6 (7) (1968) 1313–1319

R. G. Ghanem, P. D. Spanos, Stochastic Finite Element Method: Response Statistics, Springer New York, New York, NY, 1991, 101–119. doi:10.1007/978-1-4612-3094-6_4.

D. Xiu, G. Karniadakis, The Wiener-Askey polynomial chaos for stochastic differential equations, *SIAM Journal on Scientific Computing* 24 (2) (2002) 619_644. doi: 10.1137/S1064827501387826.
Keywords: Intrusive and non-intrusive generalized Polynomial Chaos, uncertainty propagation, Craig-Bampton method

On the monitoring of noisy data as a multidimensional shell

Martin Gagnon * [1], François Léonard [1], James Merleau [2], Dominique Tapsoba [2]

[1] Institut de recherche d'Hydro-Québec – IREQ 1800 Boul. Lionel Boulet Varennes (QC) J3X 1S1, Canada
[2] Institut de recherche d'Hydro-Québec – Canada

Based on the idea that multidimensional data is better summarized as a shell rather than a cloud, we have developed a surveillance approach that can detect with high sensitivity behaviour changes in a monitored process and alert the operator. Our methodology uses the time series of a high number of monitored indicators which we cluster together dynamically as a function of operating conditions. These clusters represent groups of similar realizations used to characterize a multidimensional manifold that can be interpolated to assess each new realization of the process behaviour. We evaluated the methodology on the data from a hydroelectric turbine. The event of interest was the loss of the turbine propeller runner cone. The results are good and the approach is able to detect the abnormal behaviour months before the event happened. We are currently looking at larger scale deployment to benchmark the approach's performance.

*Speaker

Confounding factors analysis and compensation for high-speed bearing diagnostics

Alessandro Paolo Daga * [1], Luigi Garibaldi [1], Alessandro Fasana [1], Stefano Marchesiello [1]

[1] Politecnico di Torino – Italy

In recent years, machine diagnostics through vibration monitoring is gaining a rising interest. Indeed, in the literature many advanced techniques are available to disclose the fault establishment as well as damage type, location and severity. Unfortunately, in general, these high-level algorithms are not robust to operational and environmental variables, restricting the field of applicability of machine diagnostics. Most of industrial machines in fact, work with variable loads, at variable speeds and in uncontrolled environments, so that the finally measured signals are often non-stationary. The very common time-series features based on statistical moments (such as root mean square, skewness, kurtosis, peak value and crest factor) undergo variations related to changes in the machine operational parameters (e.g. speed, load, ...) or in the environmental parameters (e.g. temperature, humidity, ...), which can be seen as non-measured, and then latent, confounding factors with respect to the health information of interest.
In order to face such issue, statistical techniques like (in a first exploratory stage) the Principal Component Analysis, or the Factor Analysis, are available. The pursuit of features insensitive to these factors, can be also tackled exploiting the cointegration property of non-stationary signals.

In this paper, the most common methods for reducing the influence of latent factors are considered, and applied to investigate the data collected over the rig available @DIRG Lab, specifically conceived to test high speed aeronautical bearings monitoring vibrations by means of 2 tri-axial accelerometers while controlling the rotational speed (6000 – 30000 RPM), the radial load (0 to 1800 N) and recording the lubricant oil temperature.
The compensation scheme is based on two procedures which are established in univariate analyses, but not so well documented in multivariate cases: the removal of deterministic trends by subtraction of a regression, and the removal of stochastic trends in difference stationary series by subtraction of the one-step ahead prediction from an autoregressive model. The extension of these methods to the multivariate case is here analysed to find an effective way of enhancing damage patterns when the masking effect due to the non-stationarities induced by latent factors is strong.

*Speaker

Smart Structures

EMBEDDED SENSING MICRO-COMPONENTS FOR FIBRE REINFORCED COMPOSITE MATERIAL SYNTHESIS AND MONITORING

Olivier Bareille [1], Michelle Salvia [2], Mingfa Zhang [3], Xiaopeng Cui * [4]

[1] Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) – Ecole Centrale de Lyon – 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France
[2] Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) – CNRS : UMR5513, Ecole Centrale de Lyon – 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France
[3] Laboratoire de Tribologie et Dynamique des Systèmes – Ecole Centrale de Lyon : UMR5513 – France
[4] Laboratoire de Tribologie et Dynamique des Systèmes – Ecole Centrale de Lyon, Ecole Nationale des Travaux Publics de l'Etat, Ecole Nationale d'Ingénieurs de Saint Etienne, Centre National de la Recherche Scientifique – France

The failure of materials involved in large infrastructures, such as bridges or roads, may cause a huge loss of life, economy or a loss of services An attractive solution to upgrade existing infrastructures and increase their life-span is to bond fibre reinforced thermosetting composite patches to strengthen the damaged structure and to prevent failure growth. And in doing so, understanding the properties as well as failure mechanism of the bonded thermosetting composites is essential. Initiations and growths of defects occur during almost all life of the composite up to final failure which occurs by coalescence of previous damages (cumulative damage). Hence, how to detect the latent cracks in materials and how to fix the damaged materials with more cost-effectively ways are research emphasizes.
As a non-destructive inspection method, in-situ Structural Health Monitoring (SHM) implies the use of sensors, such as piezoelectric ceramics (PZT), which are embedded within a structural material and provide real time performance feedback based on the measurement, such as electrical impedance. These sensors can be used to monitor the health state of thermosetting composites, from their curing process to the propagation of microcracks then to the end of their life cycle, which is useful for analyzing the fabrication or failure procedure of materials. By monitoring the change in the impedance spectrum which is linked to the changes of matrix viscoelastic properties as cure progressed, the different steps of the epoxy cure regarding molecular motion, viscosity, crosslinking density and their consequences on the mechanical properties of the material can be understood.

In this work, the resin for fabricating the patch composite is designed for ambient temperature cure. Its prepolymer is a low molecular weight "green" epoxy resin that made from bio-based epichlorhydrine. The hardener used is Cardolite NX5619, a solvent-free, low viscosity phenalkamine curing agent made through the Mannich reaction of cardanol from cashewnuts, formaldehyde, and amines. The natural fiber used is flax, and a quasi-unidirectional fabric made

*Speaker

of untwisted rovings was used. The weft and warp ratio is 9/91 and the areal density is 200 g/m2. The manufacturing of the natural fibers reinforced epoxy composite was accomplished by the use of wet hand lay-up process (2 plies) at room temperature.

For monitoring purpose (curing and damage), small PZT ceramic disks (0.2 mm thick disk with a diameter of 7 mm) were embedded in the composite materials during manufacturing at room temperature. The change in the impedance spectrum which is linked to the changes of matrix viscoelastic properties as cure progressed was used to follow the different steps of the epoxy matrix cure.
The results showed that the piezoelectric transducers are well suited to in-situ monitor the reaction progress during isothermal curing of a flax reinforced epoxy materials. After curing, the sensor was used as damage detector. In order to assess the efficiency of such a system for health monitoring, tests were performed based on tensile measurements using digital image correlation (DIC), classical acoustic emission and scanning electron microscope (SEM).

Temperature control of a composite core for adaptive stiffness and damping

David Renault [1], Pauline Butaud [1], Morvan Ouisse * [1], Benoît Verdin [1], Gaël Chevallier [1], Eric Joseph [1]

[1] UBFC/FEMTO-ST – Univ. Bourgogne Franche-Comté, Institut FEMTO-ST CNRS – France

In this talk, a composite structure with adaptive stiffness and damping is presented. The multilayer arrangement includes a viscoelastic layer, whose mechanical properties are controlled through temperature. The temperature field is obtained through resistive layers which are embedded in the composite. Several independent zones are defined, each of them having its temperature regulated according to the expected global stiffness and damping. The space distribution of the temperature is optimized through numerical simulations based on multiphysics finite elements. Experiments are finally shown to illustrate the applicability of the concept.

*Speaker

Vibration Control of Cable-Driven Parallel Robot for 3D Printing

Florian Lacaze * [1], Simon Chesne [1], Didier Remond [1]

[1] INSA Lyon - LaMCoS – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France., Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France – France

These last years, the additive manufacturing and 3D printing technologies have known some major breakthroughs. The motion of a printer head can be made with cable transmission. The deployment of the cable-driven parallel robots (CDPR) in the industry is studied in very various application fields for their low cost and large workspace. Furthermore, the use of cables for the transmission induces a reduction of the mobile parts' masses, compared to a rigid transmission, which enables to reach higher accelerations. Moreover, the structure of a CDPR is modular and reconfigurable thanks to the repositioning of the actuators' anchor points. However, the lack of rigidity of a CDPR raises issues of accuracy and the rise of vibrations, which can be generated by the trajectory of the mobile parts, the actuators, the friction between pulleys and cables or disturbances.

Several dynamic models of cables have been studied to understand the vibrating behaviour of a CDPR: a simple elastic model of springs with positive tensions, a lumped mass-spring model and a finite elements model based on a continuous one for the cables dynamics. The numerical simulation of the dynamic behaviour of the CDPR with these models enables the analysis of an appropriate control system and the design of a controller. It aims at ensuring an accurate positioning and a decrease of vibrations.

In this contribution, we will firstly present the dynamic behaviour's model and the issue of the actuation's redundancy, systematically present on these robots to guarantee stiffness with the tension in the cables. A comparison will be done between the effects of the models on the conception and the performance of the controller. Thus, we explain that significant decreases in the vibration levels may be observed with the use of PID controllers. The generalisation of the command, the use of active control technologies and an experimental validation will be the next steps of this study.

*Speaker

Tuesday

Angular approaches

NUMERICAL AND EXPERIMENTAL LOADS ANALYSIS ON A HORIZONTAL-AXIS WIND TURBINE IN YAW

Francesco Castellani [1], Davide Astolfi * [1], Francesco Natili [1], Matteo Becchetti [1]

[1] University of Perugia – Italy

The yaw behaviour of horizontal-axis wind turbines has been recently attracting an impressive attention in the wind energy literature. This is motivated by the fact that the active control of the yaw is the keystone of wind farm control for wake steering, in order to improve the energy production and to mitigate mechanical loads.
On these grounds, the main topic of this work is the numerical and experimental study of a three-bladed horizontal-axis wind turbine prototype in yaw. The wind turbine prototype has 2 meters of rotor diameter; the nacelle mass is 40 kg; the blades are in polymer reinforced with glass fibers and have fixed pitch angle; the maximum producible power is 3 kW. The numerical simulations are performed using the open-source aeroelastic code FAST (Fatigue, Aerodynamics, Structures and Turbulence), developed at the NREL (National Renewable Energy Laboratory). The experimental analysis is performed at the wind tunnel of the University of Perugia: it is an open test section with turbulence intensity lower than 0.5%. The prototype wind turbine has been subjected to steady wind time series, with varying yaw angles.

This work is focused on the analysis of the mechanical loads, especially as regards how they change depending on the yaw angle. A triaxial accelerometer and a load cell have been employed, for measuring the fore-aft vibrations and the force on top of the tower. The measured vibration and acceleration spectra are compared against the numerical simulations: peculiar attention is devoted to monitoring the cyclic contributions through the order-spectrum analysis. In particular, the contribution from the first blade passing frequency 3P provides meaningful information about how the blade-tower interaction varies depending on the yaw angle. The time-synchronous averaging TSA of the signals allows studying the dependence of the thrust on the azimuth angle and it arises that, above a critical velocity of the order of 10 m/s, the effect of the blade deflection on the tower dam (thrust cyclic fluctuations) can't be disregarded and therefore should be included in the numerical simulations for a reliable comparison against measurements.
The general outcome of the present work regards on one side the comprehension of the limits of low-fidelity numerical models in reproducing the mechanical behaviour of horizontal-axis wind turbines in yaw, even under steady conditions; on the other side the monitoring of mechanical loads under controlled conditions might be inspiring for the comprehension of the behaviour in real (turbulent) environments and for the development of reliable control yaw control strategies.

*Speaker

Monitoring of dynamic lifting cables for diagnosis

Souha Khadraoui * [1], Fabrice Bolaers [2], Jean Paul Dron [2], Olivier Cousinard [3]

[1] Groupe de Recherche en Sciences Pour l'Ingénieur – Université de Reims Champagne-Ardenne, Université de Reims Champagne-Ardenne – France
[2] Groupe de Recherche en Sciences Pour l'Ingénieur – Université de Reims - Champagne Ardenne : EA4694 – France
[3] Groupe de Recherche en Sciences Pour l'Ingénieur – Université de Reims Champagne-Ardenne, Université de Reims Champagne-Ardenne – France

Lifting cables are complex flexible structures, used in many technical applications, such as cranes, lifts, elevators, etc. In general terms, a cable is a set of metal wires which constitutes a single body working element. These wires are braided on one or more layers, usually around a central wire, forming the strands which, in turn, are braided around a core, and form the lifting cable. Due to their complex design and critical safety requirements, cable diagnosis remains a significant problem. In addition, cables can have a healthy appearance on their visible lengths but be damaged in inaccessible parts (for example, anchors). Indeed, it must be considered that a cable is a wear element with a limited life. Many of its mechanical properties change during its service life resulting in a decrease in the diameter caused by abrasion, corrosion, wire failures and also cable deformation. To ensure the safety of cables, there are many types of controls that are applied in practice. The most recently used technique, vibration, does not allow this system to be diagnosed below a certain speed ; Acoustic emission is expensive and requires a huge storage memory and specific algorithms ; Electromagnetic methods are also expensive and are not completely reliable, especially in the case of strand defects. From this observation, this paper proposes a specific monitoring methodology, confronting with a detection method already tested by our laboratory on rotating mechanical components, based on the measurement of angular speed variations. The diagnosis of defects, by the analysis of instantaneous angular velocity signals, is based on the fact that a defect generates a repetitive variation of the shaft speed related, to the mechanical component presenting this defect. Tests consist in investigating the behaviour of the shaft speed, in the case of absence of defects as well as in the presence of different types of cable defects. We propose the hypothesis that the variation of the instantaneous speed induced by the presence of a defect on the surface of the cable, is the consequence of the instantaneous variation in the load distribution during the passage of the pulley in the defect. It is assumed that this instantaneous variation of load distribution causes an instantaneous variation of the motor torque. Several conditions of speeds and loadings, as well as different types and sizes of defects are considered in our tests. A numerical post-analysis of the experimental data obtained allows to evaluate the performance of the proposed methodology.

*Speaker

Gears and Bearings faults Detection: from Instrumentation to Classification

Renaud Bertoni * [1], Sylvain Barcet [2], Alexandre Carbonelli [2], Marion Cortes [3]

[1] VIBRATEC (VIBRATEC) – vibratec – 28 CHEMIN DU PETIT BOIS, 6930 ECULLY, France
[2] Vibratec – vibratec – France
[3] VIBRATEC – Vibratec, vibratec – France

Gears and bearings, used in many industrial areas are subject to failure that may lead to costly shutdowns. The current trend is to detect failures (cracks, spall, pitting ...) and to identify and control their evolution. Such monitoring leads to a huge amount of data. With a double skill in test and simulation, Vibratec proposes an approach based on measurements coupled with Machine Learning (ML) processing.
This presentation defines the fault detection global approach used by Vibratec, from signal acquisition to the classification of indicators. The methodology is firstly applied on a specific HMS test bench. Then, the machine learning strategy is deployed on a database. The numerical simulations are in good agreement with the measurement results obtained on the test bench, and the machine learning indicators provides encouraging results. In the upcoming months, this complete methodology will be applied on a collaborative project aiming to improve the maintenance of aircraft engines.

*Speaker

Ball bearing diagnostics based on statistical metrics of cyclostationarity

Fabrizio Pancaldi , Rubini Riccardo [1], Marco Cocconcelli * [1]

[1] Department of Science and Engineering Methods, University of Modena and Reggio Emilia (DISMI-UNIMORE) – Via G. Amendola, 2 - Pad. Morselli 42122, Reggio Emilia, Italy

The mathematical model of faulted ball bearings has been extensively investigated in the last decades and the most recent results can even consider the kinematics of their components. So far, it is widely accepted that a faulted bearing is subject to an unwanted slippery in working conditions and this leads to a cyclostationary vibration signal [1]. Several works available in the technical literature are devoted to early detection of faults on the basis of the cyclostationary signature of the ball bearing [2]. This paper compares different approach to the ball bearing diagnostics based on the statistical definition of cyclostationarity [3]. In particular, few metrics have been devised to track the cyclic frequencies of the vibration signal. These metrics are: time-varying variance, time-varying kurtosis, time-varying Kolmogorov-Smirnov test. As reference, spectral kurtosis demodulation and autocorrelation are also included in the comparison since they are among the most used techniques in condition monitoring so far. The performance of the proposed algorithms has been assessed on experimental measurements (Figure 1). The comparison is completely automatized, avoiding subjective judgment of the technician. Numerical results have shown that the simplicity of the proposed algorithms leads to an intrinsic robustness against the mechanical noise typical of practical scenarios; nonetheless the computational complexity is very limited and is compatible with low end electronic equipment.
Keywords: Condition monitoring, Ball bearing, Variance, Kurtosis, Kolmogorov-Smirnov

C. Capdessus, M. Sidahmed, and J. L. Lacoume, "Cyclostationary processes: Application in gear faults early diagnosis," Mechanical Systems and Signal Processing, vol. 14, no. 3, pp. 371 – 385, 2000.

I. El-Thalji and E. Jantunen, "A summary of fault modelling and predictive health monitoring of rolling element bearings," Mechanical Systems and Signal Processing, vol. 60, pp. 252–272, 2015.

W. A. Gardner, A. Napolitano, and L. Paura, "Cyclostationarity: Half a century of research," Elsevier Signal Processing, vol. 86, pp. 639 – 697, 2006.

*Speaker

Measurement and use of transmission error for diagnostics of gears

Robert Randall [1], Zhan Yie Chin [2], Wade Smith [2], Pietro Borghesani * [2]

[1] School of Mechanical and Manufacturing Engineering University of New South Wales – Sydney 2052, Australia

[2] School of Mechanical and Manufacturing Engineering University of New South Wales – Australia

Transmission error (TE) has long been thought to be a major contributor to gear vibration and noise, but insufficient consideration has been given to the different types of TE and how they generate vibrations. TE is defined as the difference in torsional vibration of two meshing gears, scaled so as to represent linear motion along the line of action, this being common to the two gears, as opposed to the corresponding variations in angular displacement, inversely proportional to the pitch radii. There are three distinct types of TE, with different origins and properties: 1) Geometric TE (GTE) given by deviations of the (combined) tooth profiles from ideal involute 2) Static TE (STE) including elastic deformation of the teeth and therefore being load dependent 3) Dynamic TE (DTE) where the loads on the teeth depend on the dynamics of the system, and thus include inertial as well as stiffness effects, so that they vary with speed for frequencies above the lowest resonance. It has long been recognized that TE can be measured very accurately by phase demodulation of the signals of shaft encoders rigidly attached to each of the gears in mesh. The encoders can be mounted on the free ends of the gear shafts (the section not transmitting torque).
It has recently been realized that all three types can be measured; GTE at low speed and low load, STE at low speed and higher load, and DTE at higher speed and higher load, as long as the machine can be operated over a range of speeds and loads. Compared with measurements of the actual angular motions from which the TEs can be calculated, the TEs are much more repeatable, because the two gears follow the same small speed variations, which cancel out in the TE.

Measurements have been made on a single stage gearbox, with hardened and ground spur gears, over an input gear speed range from 2 – 20 Hz, and input shaft torque range from 0 – 20 Nm. Heidenhain ROD426 shaft encoders were used, with 1000 pulses per rev, as well as a one per rev tacho pulse as a phase marker. A simulated tooth root crack has been inserted in one tooth on the input pinion. One of the four bearings had an inner race fault, but in this case that can be considered as part of the background noise. Other projects involve diagnosing the gear and bearing faults separately when both are present at the same time.

A previous paper [1] was made with the same basic test rig (though with a different gear set and naturally developing pitting over an operating period of many hours). Unfortunately, the encoders used at that time (actually included in slip rings) had a low torsional resonance frequency, which precluded making measurements at higher than 2 Hz shaft speed, so only GTE

*Speaker

and STE could be estimated, the latter only at zero and 20 Nm load. The results were promising, but could not show dynamic effects.
The results of the current tests show that the measured GTE, STE, and DTE behave as might be expected, and correspond well with a lumped parameter simulation model of the test rig, for both TE and acceleration responses. The indications are that TE has several advantages over vibration acceleration (or even the raw torsional vibrations) as a diagnostic parameter, being close to the source (the gearmesh) and with "common mode rejection" from the two gears, thus being much less sensitive to operating conditions and rig parameters, including the much greater number of transfer paths, modulations, and resonances in the casing vibration measurements.

Rolling bearing diagnosis based on H_infinity filter order tracking

Amadou Assoumane * [1], Dany Abboud [1], Sekko Edgard [2], Mohamed El Badaoui [3]

[1] SAFRAN GROUP – SAFRAN (FRANCE) : SafranTech – France
[2] Laboratoire PRISME (PRISME) – Université d'Orléans : EA4229 – 21 rue Loigny la Bataille, 28000 Chartres, France, France
[3] Laboratoire d'Analyse des Signaux et des Processus Industriels (LASPI) – Université Jean Monnet - Saint-Etienne : EA3059 – France

The analysis of the squared envelope spectrum (SES) is one among the most used tools for bearing diagnosis. It can easily reveals the characteristic frequencies related to the bearing fault. Actually, the envelope is estimated through a demodulation process in a selected frequency band. The proper choice of the latter is really challenging in a complex environment . In addition to that, the frequency of the bearing fault is likely to be masked by deterministic components. This can jeopardize the efficiency of classical techniques. In this paper, a new approach for bearing diagnostic is proposed. It is based on a recently proposed order tracking technique using the H_infinity filter. In details, the method starts by computing the squared envelope (SE) of the raw signal over the full demodulation band without prior processing. Next, the SE is modeled in a state space using a Fourier series expansion. Last, an H_infinity estimator is designed to extract the amplitude of each harmonic related to the bearing fault signature.
This estimator is well convenient to track the order of bearing faults, particularly in the presence of deterministic components (i.e. the noise). Since this noise is not white and Gaussian, the traditional Kalman filter order tracking is compromised. Contrary to the Kalman filter, the H_infinity filter is based on the minimax optimization. The minimax approach leads to the minimization of the estimation error for the worst possible amplification of the noise signal. More interestingly, no prior knowledge about the statistical properties of the noise signals is required. The efficiency of the proposed approach is demonstrated on simulated and real-world vibration signals in nonstationary regimes.

*Speaker

Dynamic Characterization Of Hydroelectric Turbine In Transient Using OBMA And Phase-Shift Analysis

Quentin Dollon * , Souheil-Antoine Tahan [1], Jérôme Antoni [2], Martin Gagnon [3], Christine Monette [4]

[1] Ecole de Technologie Supérieure (ETS) – 1100, rue Notre-Dame Ouest Montréal (Qc) H3C 1K3 Canada, Canada
[2] Institut national des sciences appliquées de Lyon (INSA Lyon) – INSA Lyon – 20 Avenue Albert Einstein, 69621 Villeurbanne cedex, France
[3] Institut de recherche d'Hydro-Québec – IREQ 1800 Boul. Lionel Boulet Varennes (QC) J3X 1S1, Canada
[4] Andritz Hydro Ltd – Canada

Design and exploitation of hydroelectric turbines relies on the knowledge of their dynamic behavior. This last enables one either to get a good assessments of life duration or to set up predictive-based maintenance sessions. In needed, two sources of information are mandatory to characterize the mechanical behavior of a structure: numerical simulations, and experimental data processing. The first field gives a whole and detailed analysis of the behavior in any expected regime, but needs to be validated by the second to be reliable, which is a straightforward consequence of the strong assumptions made to reduce computing burden. The second method aims at achieving *in-situ* measurements to extract dynamic features; these features will be highly fragmented, but in general closer to reality for a given measured operating condition. These two sources of information are then crossed to obtain a hybrid representation of the dynamic behavior.
However, one of the problems with experimental analysis is the cost of data acquisition. To reduce financial burden of measurements, the idea is to extract a maximum of information from transient records instead of several stationary records, which would make the measurement less time consuming. Our goal is to determine whether the signal processing is able to extract precise and suitable features from these transient measurements.
The purpose of this paper is to consider the possibility of extracting modal parameters of a Francis hydroelectric turbine in transient conditions by focusing on resonance regions generated by the interaction of a structural mode with a frequency-variant harmonic pressure pulsation. Especially when numerous modes are in the same bandwidth, this method separates them by exciting only matching shapes. The resonance retrieval is done using Order Tracking (method used to extract a specified harmonic from the signal), and a classical Modal Identification algorithm is then used to feature the isolated mode. Furthermore, a phase-shift analysis is made between captors measuring resonance in order to both localize the mode and determine the shape.

*Speaker

A new method for identifying diagnostic rich frequency bands under varying operating conditions

Stephan Schmidt * [1], Alexandre Mauricio [2,3], Stephan Heyns [1], Konstantinos Gryllias [2,3]

[1] Centre for Asset Integrity Management, University of Pretoria, Pretoria, South Africa – South Africa
[2] Dynamics of Mechanical and Mechatronic Systems, Flanders Make – Belgium
[3] KU Leuven, Faculty of Engineering Science, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300 B, B-3001, Heverlee, Belgium – Belgium

The Squared Envelope Spectrum (SES) and the Improved Envelope Spectrum (IES) are some of the most powerful representations for diagnosing rotating machine components such as bearings [1, 2]. However, to ensure that the SES and the IES representations are rich with diagnostic information, it is necessary to confine the SES and the IES calculations in order to narrow the spectral frequency bands that contain the required diagnostic information [2]. Various methods have been proposed in order to automatically identify the appropriate frequency band for fault detection and diagnosis such as the kurtogram [3], the infogram [4] and the sparsogram [5]. This is usually performed by decomposing the signal into a range of bandlimited signals and selecting the frequency band that maximises a metric, i.e. the kurtosis [3].

Machines such as wind turbine gearboxes inherently operate under time-varying operating conditions and could operate in an environment with transients unrelated to the machine component being monitored (e.g. a spurious impulse). These phenomena could adversely affect the performance of the frequency band identification techniques. For example, the presence of transients unrelated to the machine condition can lead to the identification of a suboptimal or wrong frequency band when metrics such as the kurtosis [4] are used.

Hence, in this paper a new Frequency Band Identification Tool (FBIT) is proposed which is suited for signals acquired under non-stationary operating conditions. This FBIT is used to automatically identify the frequency band that contains the signal of interest and the most information related to a specific damage mode of a machine component (e.g. ball pass cyclic order of a bearing and its harmonics).

In this FBIT, the signal is also paved into a spectral frequency-frequency resolution plane, but instead of calculating a metric of the signals based on multiple short-time Fourier transforms or a wavelet packet decomposition, a metric is calculated from the data based on multiple order-frequency spectral coherences. This is motivated by the fact that the order-frequency spectral coherence is a very powerful representation for detecting fault signatures of bearings and gears under time-varying operating conditions and it preserves the angle-time cyclostationary properties of the fault signatures as well. Also, a different metric is used compared to conventional

*Speaker

approaches. Instead of calculating a metric of the whole narrowband signal (e.g. kurtosis) which may be sensitive to unrelated outliers (e.g. spurious impulse), a metric is calculated which represents the strength of the specific cyclic component in the signal and by optimising also the window resolution of the spectral coherence. This allows the selection of the optimum frequency band for the identification of the cyclic component under investigation (e.g. for identifying outer race bearing damage).

The proposed FBIT is investigated on numerical bearing data, generated from a phenomenological gearbox model under time-varying speed conditions, as well as on experimental gearbox data, acquired under varying speed and load conditions.

Keywords

Gearbox fault diagnosis; Order-Frequency Spectral Coherence; Frequency Band Identification

References

Abboud, D. et al., 2017. Envelope analysis of rotating machine vibrations in variable speed conditions: A comprehensive treatment. Mechanical Systems and Signal Processing, 84, pp.200–226.

Abboud, D. & Antoni, J., 2017. Order-frequency analysis of machine signals. Mechanical Systems and Signal Processing, 87(October 2016), pp.229–258.

Antoni, J., 2007. Fast computation of the kurtogram for the detection of transient faults. Mechanical Systems and Signal Processing, 21(1), pp.108–124.

Antoni, J., 2016. The infogram: Entropic evidence of the signature of repetitive transients. Mechanical Systems and Signal Processing, 74, pp.73–94.

Tse, P.W. & Wang, D., 2013. The design of a new sparsogram for fast bearing fault diagnosis: Part 1 of the two related manuscripts that have a joint title as "two automatic vibration-based fault diagnostic methods using the novel sparsity measurement - Parts 1 and 2." Mechanical Systems and Signal Processing, 40(2), pp.499–519.

Diagnostics and Dynamic models

Challenging the multiplicative model used for gear vibration

Elisa Hubert [2,1], Pietro Borghesani * [3], Axel Barrau [4,1], Mohammed El Badaoui [2,1], Robert Randall [3]

[2] Laboratoire dÁnalyse des Signaux et des Processus Industriels – Université Jean Monnet [Saint-Etienne] : EA3059 – France
[1] SAFRAN Tech – SAFRAN (FRANCE) – France
[3] University of New South Wales [Sydney] – Australia
[4] École des Mines de Paris – Centre for industrial economics, école des mines de Paris – France

Context:

Health monitoring for gears is traditionally based on vibration analysis. It is generally assumed in both the literature and within the community that gear vibrations can be modelled (at least in their amplitude modulation component) by the following multiplicative model [1].

where is a reference shaft angle, represents the gearmesh, and and are the modulating effects of the two gears and represent the variability of the engagement due to imperfections in the gear teeth. All components in this model are considered to be multi-harmonic with fundamental frequencies respectively.

According to this model, the spectrum of the signal should be characterized by a series of peaks at the gearmesh harmonics , each with modulation sidebands and .

Experimental investigation:

The established model may be an interesting approximation at first sight but our experimental investigation has shown several inconsistencies.

First, there are sidebands present in the spectrum at the crossed frequency . This is actually justified by the fact that a model

is more physically rigorous, i.e. the combined effect of the two gears must have a periodicity which corresponds to the event of the same two teeth meshing again.

Secondly, all the experimental spectra show that the ratio between the sidebands of different gearmesh harmonics is not constant, even after a precise order-tracking using an encoder with a high number of pulses. There are several hypotheses regarding the explanation for this difference.

The transfer function.

*Speaker

The transfer function between excitation and actual measurement is the obvious suspect for this distortion. However, even after applying a cepstral long-pass lifter (aimed at removing the transfer function "scaling" of the spectrum), the differences between sideband patterns remain strong.

Simultaneous effect of tooth stiffness and geometric profile error

A more subtle hypothesis instead involves the consideration of two effects resulting in the modulation of the gearmesh. Under this hypothesis, tooth-stiffness-induced vibrations (load dependent) and vibrations induced by profile error (independent of load) are acting as two parallel models, with different carriers and modulations, but coincident frequencies. Under this assumption the gearmesh harmonics show different combined patterns of sidebands because of the additive effect of two different gearmesh carriers and modulations.

Different operating conditions and test-rig layouts will be used in this paper to validate these assumptions and identify modelling limitations.

C. Capdessus, "Aide au diagnostic des machines tournantes par traitement du signal (Aid to the diagnosis of rotating machines by signal processing)," 1992.

Detection sensitivity study of local faults in spur gears based on realistic simulations

Lior Bachar * [1], Ido Dadon [1], Renata Klein [2], Jacob Bortman [1]

[1] PHM Laboratory, Department of Mechanical Engineering, Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 8410501 – Israel
[2] R.K. Diagnostics, P.O.B. 101, Gilon, D.N. Misgav 20103 – Israel

Keywords: Gear Model, Vibration Signature, Condition Monitoring, Local Tooth Fault, Spur Gear, Gear Diagnostics, Statistical Analysis
The dynamic response of gear transmissions holds essential information for the recognition of an incipient fault and its propagation. A realistic and validated dynamic model is used to predict the vibration regime of gear transmissions. A great virtue of a model is the ability to examine each phenomenon separately and isolate its contribution to the dynamic response. This paper presents the analysis of local tooth faults in spur gear transmissions. The model considers the nonlinear behavior of the gear mesh stiffness, integrating the geometric profile errors of the gears. The scattering in the data, which is generated by the random factor of the simulated surface roughness, simulates the reality better than data of an ideal profile. The ability to determine what is possible to monitor for each surface roughness is not trivial at all. It cannot be achieved experimentally, due to the immense span of cases to consider. The thoughtful insights from the simulated vibration signatures were drawn from a set of features, which made it possible to examine the detection capability in different operating conditions including speed, load and surface roughness. This comprehensive analysis may yield the ability to fit a robust and sensitive monitoring process for different operation conditions and faults. Moreover, investigating by the use of simulations shade a new light on understanding the physical phenomena. A matrix of hundreds of simulations was used to assess the capability to discriminate between health status of the gear and detectability of different fault severities.

[**1**] DADON, I., et al. A realistic dynamic model for gear fault diagnosis. Engineering Failure Analysis, 2018, 84: 77-100.

[**2**] N. Koren, I. Dadon, J. Bortman, R. Klein, Steps toward fault prognostics of gears, in: C. MFPT, 2016: pp. 10–15. doi: 10.1784/204764217820440991.

[**3**] F. Chaari, T. Fakhfakh, M. Haddar, Analytical modelling of spur gear tooth crack and influence on gearmesh stiffness, Eur. J. Mech. A. Solids 28 (3) (2009) 461–468 1, 1.

[**4**] D. Yang, J. Lin, Hertzian damping, tooth friction and bending elasticity in gear impact dynamics, J. Mech. Des. 109 (2) (1987) 189–196 1, 2.1.2, 2.1.2, 2.1.2.

[**5**] P. Velex, M. Maatar, A mathematical model for analyzing the influence of shape devia-

*Speaker

tions and mounting errors on gear dynamic behaviour, J. Sound Vib. 191 (5) (1996) 629–660 1, 1, 2.1.1,2.

[**6**] N.M. Newmark, A method of computation for structural dynamics, Proc. ASCE, vol. 85, 1959, pp. 67–94 2.2.

[**7**] Yang, Y., Smith, W. A., Borghesani, P., Peng, Z., & Randall, R. B. (2015). Detecting changes in gear surface roughness using vibration signals. In Acoustics 2015.

[**8**] ANDRADE, F. A.; ESAT, I. I.; BADI, M. N. M. Gear condition monitoring by a new application of the Kolmogorov-Smirnov test. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 2001, 215.6: 653-661.

[**9**] SHARMA, Vikas; PAREY, Anand. A review of gear fault diagnosis using various condition indicators. Procedia Engineering, 2016, 144: 253-263

Towards a better understanding of helical gears vibrations – dynamic model validated experimentally

Nadav Silverman * [1], Ido Dadon [2], Renata Klein [3], Jacob Bortman [4]

[1] Ben Gurion University – Israel
[2] Ben Gurion University – Israel
[3] R.K. Diagnostics – Gilon, P.O.B. 101, D.N. Misgav 20103, Israel
[4] PHM Lab, Department of Mechanical Engineering, Ben-Gurion University of the Negev, – P.O. Box 653, Beer Sheva 84105, Israel

In order to simulate the vibration signature of gears, an accurate calculation of the gear mesh stiffness (GMS) is required. The time varying GMS, which is the main excitation that determines the dynamic response of transmissions' vibrations, is well understood for spur gears, but that of helical gears was less investigated. Although there is work dedicated to helical gears vibrations, a comprehensive analysis of their GMS compared to spur gears and their time and spectral domains have yet to be made. This paper deals with the dissimilarities and provides a better understanding of helical gears behavior, as they are a key component in many complicated and costly machines. With this new knowledge a more educated approach to diagnostics might be achieved.

The main difference between spur and helical gears is in the contact line pattern. In spur gears the contact line is parallel to the tooth's base and so calculating the GMS in any given moment is rather easy. Helical gears on the other hand have a diagonal line of contact which makes the moment applied by the meshing gear in respect to the tooth's base change along the tooth's width. To overcome this challenge a 'multi slice' method is utilized [1-4], in which the helical tooth is divided into many infinitesimally narrow slices which are treated each as a spur tooth. The total helical tooth stiffness is the sum of all those spur slices.

For the purpose of simulating the vibrations of helical gears a fourteen degree of freedom spur-teeth dynamic model [5] was upgraded to include helical gears a well. The dynamic equations and stiffness calculation were not changed and thus are discussed only briefly. The focus is dedicated to the modeling of the contact line using the multi slice method and other adjustments made to the model.

The challenge with the slice method is determining how many slices are in mesh at every given time, along with determining their mesh "height" (distance from the tooth's base). The solutions found in the literature are rather complicated and require knowing niche data about the gears, such as the transverse operating pressure angle, which are often not provided by the manufacturer. In contrast, the method suggested in this work is based on only a few common parameters such as the gears module, number of teeth and the involute profile.

*Speaker

The model was validated by an experiment conducted on a helical gearbox and recorded with a tri-axial accelerometer. The signals were compared in terms of their load and RPM dependency and exhibited a similar behavior. After obtaining a healthy baseline, a broken tooth case with three severity levels was studied. The fault severities were removal of 25% of the tooth's width in a diagonal line, removal of 50% and a missing tooth (Figure 1). This kind of diagonal material removal was chosen because when helical teeth breaks it happens in a pattern parallel to the contact line. The light and medium fault were challenging, but the missing tooth was seen clearly, mainly in the Kurtosis and Crest Factor of the difference signal. The statistical distances of the SA spectrum around the first and fifth GM harmony proved to provide better sensitivity, and showed clear detection of various fault severities, mainly in the tangential direction. A calculation of the Z-score index around the first GM even showed capability of ranking by fault severity (Figure 2).

Keywords: Helical gears, Dynamic model, Multi-slice method, Broken tooth.

Bibliography

- Smith, J. D. "Estimation of the static load distribution factor for helical gears." Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science209.3 (1995): 193-199.
- Chen, Kangkang, et al. "Comparison of meshing characteristics of helical gears with spalling fault using analytical and finite-element methods." Mechanical Systems and Signal Processing121 (2019): 279-298.
- Wang, Qibin, et al. "An improved time-varying mesh stiffness model for helical gear pairs considering axial mesh force component." Mechanical Systems and Signal Processing 106 (2018): 413-429.
- Wang, Qibin, and Yimin Zhang. "A model for analyzing stiffness and stress in a helical gear pair with tooth profile errors." Journal of vibration and control 23.2 (2017): 272-289.
- Dadon, I., et al. "A realistic dynamic model for gear fault diagnosis." Engineering Failure Analysis 84 (2018): 77-100.
- Dadon, I., et al. "A Step Toward Fault Type and Severity Characterization in Spur Gears." Journal of Mechanical Design141.8 (2019): 083301.

Modeling and identification of mechanical systems

Numerical and experimental analyses to enhance the vibration response of rotary transfer machines

Marco Troncossi [1], Alberto Martini * [1], Nicolò Vincenzi [2], Alessandro Rivola [1]

[1] University of Bologna - Department of Industrial Engineering (DIN) – Italy
[2] GIULIANI – a Bucci Automations SpA Division – Italy

This work deals with the elastodynamic analysis of rotary transfer machines. Such systems are machine tools conceived for the mass-production of families of components. They typically feature a rotary indexing table carrying the workpieces and multiple machining units operating simultaneously [1]. Cutting forces between tools and workpieces and rapid motion of both the indexing table and the machining units can excite the system resonances in a wide frequency range and trigger elastodynamic phenomena possibly detrimental for both the quality of machined surfaces and the tool life. Assessing and solve potential vibration issues is therefore essential to ensure the correct operation of the machine tool.
The study focuses on a new machine tool designed for machining components for the lock&keys industry
(Fig. 1). It features ten functional stations and fifteen CNC machining units (nine located on the main structure, six on external supports). The manufacturer aims at reducing the vibration levels by improving the current design of the machine tool. Two strategies are investigated to attain the goal. The first (more conventional) approach consists in optimizing the vibration response of the system through changes of the geometry and/or the inertial properties of its structure and/or subassemblies. A Finite Element model of the whole machinery was implemented to evaluate the effects of possible modifications (e.g. additional stiffeners), by performing numerical modal analyses. The model was validated through Experimental Modal Analysis (EMA) to achieve an adequate reliability. EMA was carried out by considering about 30 measuring points as well as a highly redundant dataset. Indeed, numerous signals were required to correctly identify the mode shapes, due to the high modal density of the system. Moreover, redundant data were exploited for comparing the results provided by different subsets, in order to determine the most effective subset for estimating the modal parameters (since exciting properly the system proved a challenging task, due to its complexity).

The second strategy is based on the use of polymer concrete for filling some of the primary structures of the machine tool to increase their damping [2]. The study (still at an early stage) started with experimental tests to assess the effects of polymer concrete on the damping parameters of simple profile bars. Further experiments with more complex components of the real machine tool are being conducted.

Keywords: Experimental Modal Analysis; polymer concrete; machine tool.

*Speaker

Bifurcation Tracking and sub-harmonic isola detection in nonlinear mechanical systems

Roberto Alcorta * [1], Benoit Prabel [2], Philippe Piteau [2], Sébastien Baguet [1], Jacquet-Richardet Georges [1]

[1] Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France – Institut National des Sciences Appliquées de Lyon, CNRS : UMR5259 – France

[2] Laboratoire d'études de dynamique (CEA/DEN/DANS/DM2S/SEMT/DYN) – CEA, Université Paris-Saclay – France

Keywords: nonlinear vibrations, bifurcation tracking, period doubling, isolas

Intermittent contacts are commonplace in numerous mechanical engineering applications. Since the resulting localized forces are strongly non-linear, multiple dynamical regimes may co-exist for a given set of conditions, and small perturbations then suffice to induce a change from a desirable to a potentially unfavourable state. For this reason, prediction of global dynamics is critical, especially in regard to the systems' parameters. Numerical *bifurcation tracking* offers a means to efficiently compute stability boundaries, as done by Xie et al. [1] for systems under forced vibration. In this approach, constraints are appended to the equations of motion, and the solution of the *extended systems* thus constructed gives the loci of bifurcation points for a varying parameter. Even isolated resonance curves, which are usually difficult to detect, have been found through this technique, see e.g. Kuether et al. [2]. However, this has only been done for the case when both the regimes on the isolated and main resonance branches share a common fundamental frequency, whereas it is known that *sub-harmonic* isolated resonances are also possible for vibrating systems undergoing asymmetric contacts [3].

In the present contribution, we first propose an extended system characterizing period doubling bifurcations through the *harmonic balance method* (HBM), then proceed to track these bifurcations. We show that, given a judicious choice of tracking parameter, extremal points on the ensuing stability boundaries correspond to the birth of isolated sub-harmonic resonances. Moreover, we further characterize and track these points with respect to a second parameter. This is interesting from a design viewpoint, since it provides a way to avoid these regimes altogether. Afterwards, we present an example application on an academic system, where an "asymmetry parameter" controls the existence of sub-harmonic isolas. Finally, numerical results are confronted with experimental measurements, which validate the methods proposed herein.

References:

L. Xie, S. Baguet, B. Prabel, R. Dufour, Bifurcation tracking by Harmonic Balance Method for performance tuning of nonlinear dynamical systems, J. of Mechanical Systems and Signal Processing, 88 (2017) 445-461

R. J. Kuether, L. Renson, T. Detroux, C. Grappasonni, G. Kerschen, M.S. Allen, Nonlinear normal modes, modal interactions and isolated resonance curves, J. of Sound and Vibration, 351 (2015) 299-310

*Speaker

C. Duan and R. Singh, Isolated sub-harmonic resonance branch in the frequency response of an oscillator with slight asymmetry in the clearance, J. of Sound and Vibration, 314 (2008) 12-18

Localization and quantification of damage by frequency based methods : Numerical and Experimental applications on bending vibration beams

Anurag Dubey * [1], Vivien Denis [1], Roger Serra [1]

[1] Laboratoire de Mécanique Gabriel Lamé – Institut National des Sciences Appliquées - Centre Val de Loire : EA7494 – France

The sudden growth of damages can cause catastrophic failure of structures or mechanisms that lead to unplanned shutdowns of machines and production lines. If damage remains undetected and reaches a critical size, sudden collapses and failures can happen. To overcome these problems, it is essential to detect these damages before they reach their critical state. The presence of damages can alter the structure which reduces the bending stiffness and modify the modal parameters and the natural frequencies. One of the most suitable monitoring methods to define the presence of damage and assess the structure is vibration based structure health monitoring (VBSHM). The objective of the work is localization and quantification of damages with the consideration of eigenfrequencies of healthy and unknown structures. Different frequency-based approaches (Frequency shift coefficient (FSC), Normalized natural frequency (NNF), Frequency error function and Least frequency change ratio (LFCR)) are presented. To achieve these goals, numerical nite element models (2D and 3D FE models) are performed and correlated to obtain a damage library for the cantilever beam structure [1]. Based on several indicators (or cost functions), Young's modulus of 2D and 3D models are iteratively updated to closely match the frequencies of an experimental beam. These approaches also illustrate the localization and quantification of rectangular geometry damage by vibration measurements on cantilever beams, which is related to an equivalent bending stiffness reduction by the use of frequency shift coefficient [2]. Many damage cases are tested, where the damage was located through the different parts along the beam: near the embeddedness, at the middle, and at the end of the beam. The effect of severity of the damage is considered. The quantification is classified between FE models by changing the location and depth of the damage. Finally, results are validated experimentally through the identification of different damage cases.
Keywords: Finite element models, natural frequency, stiffness reduction, modal analysis, young modulus updating, frequency shift coefficient

References:

1. Serra, R., Lopez, L., and Gautier, G. 2016., Tentative of Damage Estimation for different damage scenarios on cantilever beam using Numerical Library, In Proceedings of the 23rd International Congress on Sound and Vibration, Athens, Greece, (pp. 10-14).
2. Silva, J.M.M. and Gomes, A.J.M.A. 1994., Crack Identification of Simple Structural Elements

*Speaker

Through the use of Natural Frequency Variations: The Inverse Problem, In Proceedings of the 12th International Modal Analysis Conference, (pp. 1728-1735).

ARX model for experimental vibration analysis of grinding process by flexible manipulator

Quoc-Cuong Nguyen * [1], Viet-Hung Vu [1], Marc Thomas [1]

[1] Mechanical Engineering Department, Ecole de technologie supérieure, Montreal (Qc), H3C 1K3 – Canada

Using a flexible manipulator for grinding process in situ has become a cost effective engineering service in the recent years, especially for repair and refurbish of mechanical systems and components. In comparison with traditional rigid robot manipulators, the flexible manipulator has proved its superiorities in terms of accuracy and efficiency. However, because of compact and flexible structure, concerns arise regarding its dynamic behavior during machining process. This paper introduces a method using an ARX (autoregressive with exogenous excitation) model to experimentally analyze the vibration by using a flexible robot during grinding operation in different cases Single Input – Single Output (SISO), Multi Input – Multi Output (MIMO). Simultaneously, a dynamometer allows for triaxial input excitations measurement while 3 accelerometers mounted at the end effector represent the vibration outputs of the whole process. Thanks to the operational modal analysis, the dynamical properties of the robot can be identified directly in operation. The results show that the ARX model is efficient for analyzing the operational vibration in complex systems with multi degrees of freedom and multi directions. The determination of modal parameters and identified Frequency Response Functions (FRFs) enable to predict the dynamical behavior of the system and to simulate the vibration in real working conditions. Further study is promising on the inverse problem to estimate the excitation forces while these later are not available and not practically measured in industrial applications.

Keywords: Operational modal analysis, flexible manipulator, grinding process, ARX model.

References:

Hazel B., J. Côté, Y. Laroche, P. Mongenot, *A portable, multi process, track-based robot for in situ work on hydropower equipment*, J. Field Rob. 28 (2012) 69–101, http://dx.doi.org/10.1002/rob.204 Vu,V.H., Z. Liu, M. Thomas and B. Hazel, *Operational modal analysis of a light-weight robot with a rotating tool installed at the end-effector*, Journal of Mechanical Engineering Science, 2016, Part C, 1:13. Söderström, T., Fan, H. H., Carlsson, B., & Bigi, S. *Least squares parameter estimation of continuous time ARX models from discrete-time data.* IEEE Transaction on Automatic Control, 1997. Chiuso A. *The role of vector autoregressive modeling in predictor-based subspace identification.* Automatica, Volume 43, Issue 6, June 2007, Pages 1034-1048. Lu Y and Gao F. *A novel time-domain auto-regressive model*

*Speaker

for structural damage diagnosis. Journal of Sound and Vibration, Volume 283, Issues 3–5, 20 May 2005, Pages 1031-1049.

Use of virtual sensors for the analysis of forces exerted by the load inside a tumbling mill

Cristián Molina Vicuna * [1], José Venegas P. [1], M. Aníbal Valenzuela [2]

[1] Laboratorio de Vibraciones Mecánicas, Departamento de Ingeniería Mecánica, Universidad de Concepción – Chile
[2] Laboratorio de Accionamientos Eléctricos, Departamento de Ingeniería Eléctrica, Universidad de Concepción – Chile

In this paper, a methodology is presented to obtain average representative forces exerted by the load inside a tumbling mill on the different faces of the lifters and liners, which are directly related to its power consumption. The methodology is based on the use of virtual sensors included in DEM simulations combined with signal processing and allows obtaining the magnitude of the forces based on the angular position of the lifters as the mill rotates. The methodology is validated by comparing numerical and experimental results obtained from a test bench mill. The variables considered are the power, movement of the load inside the mill, and average forces. The latter are experimentally measured using instrumented lifters specially designed for this task. The results obtained show differences in the magnitude of the average forces in specific angular positions, depending on the operating conditions of the mill. These differences explain the behavior of power consumption with respect to operating conditions reported in the literature.

*Speaker

Signal processing

Comparison and Improvement of Techniques for Transmission-Path Restoring

Omri Matania * [1], Renata Klein [1], Jacob Bortman [1]

[1] PHM Lab, Department of Mechanical Engineering, Ben-Gurion University of the Negev, – Israel

Authors: Omri Matania, Renata Klein, Jacob Bortman,
Keywords: vibration signal, transmission-path, pre-whitening, adaptive clatter separation (ACS), Cepstrum-liftering, AR model, restoration process.

Abstract:

Condition based monitoring by vibration sensors is a widely spread technique for monitoring the status and condition ("health") of rotating machines. In most cases the monitoring is based on the ability to isolate specific elements of the vibration signals, generated by the different rotating components.

The generated signals are propagating through various transmissions paths of the machine, that distort the original signals, hence affect the assessment of the machine condition. While these effects usually ignored by most vibration analysis techniques, first steps towards mitigating this problem have taken place during the last years. These techniques used pre-whitening methods, which usually served to separate the signal from its background as well as to reduce the transmission path effects.

In this paper we aim to go a step further in transmission path restoring through deepening our understanding of their effects on the vibration signals. We start by comparing three main pre-whitening methods: liftering low quefrencies at the Cepstrum (Cepstrum-liftering), adaptive clutter separation (ACS), and pre-whitening using auto-regressive (AR) models. First, it is shown that signal's pre-whitening by AR model has large errors and therefore is less adequate for transmission path restoration process. A theoretical approach to adjust parameters of ACS and Cepstrum-liftering techniques and examine them through quantitative methods is proposed.

The ability to utilize ACS and Cepstrum-liftering based techniques to restore the originals signals out of the measured signal is explored. Finally, the restoration quality is tested by simulation outcomes and real measured data.

References:

R. Klein, *Comparison of methods for separating excitation sources in rotating machinery*, The International Conference SURVISHNO 7, 2013.

*Speaker

R.B Randall, B. Peeters, J. Antoni, S. Manzato, *New cepstral methods of signal pre-processing for operational modal analysis*, ISMA2012-USD2012, Leuven, Belgium, pp. 775-764, 2012.

R.B. Randall, W.A Smith, *Cepstrum-based operational modal analysis revisited: A discussion on pole-zero models and the regeneration of frequency response functions*, Article in Mechanical Systems and Signal Processing (MSSP), 2016.

R.B. Randall, W.A Smith, *New cepstral techniques for operational modal analysis*, Conference Paper, 2017.

N. Sawalhi and R.B. Randall, *Spectral Kurtosis Enhancement using Autoregressive Models*, ACAM2005 conference, Melbourne, 2005.

R. Castiglione, J. Antoni, L. Garibaldi, *Separation and identification of structural modes in largely underdetermined scenarios using frequency banding*, Journal of Sound and Vibration 414 pp. 192-217, 2018.

Influence of Gaussian Signal Distribution Error on Random Vibration Fatigue Calculations

Yuzhu Wang * [1], Roger Serra [1], Pierre Argoul [2]

[1] Laboratoire de Mécanique Gabriel Lamé – Institut National des Sciences Appliquées - Centre Val de Loire : EA7494 – France

[2] Laboratoire Mast – EMGCU – IFSTTAR UMR-T 9405 – France

In the study of random vibration problems, Gaussian vibration and non-Gaussian vibrations are usually classified according to the excitation signal. The skewness and kurtosis are usually used to distinguish. Here we discuss a non-strict Gaussian signal, which is the error that exists in skewness and kurtosis and usually unavoidable in actual experiments or signals analysis. Through experiments and simulation calculations, the influence of this error on the traditional fatigue calculation method is discussed. The PSD approach will be discussed primarily, and time domain signals based on the rain-flow counting method will be recorded and verified. Total nine calculation model studied in this process. Finally, through a threshold, the range of skewness and kurtosis is indicated, that within this range, Gaussian signal-based calculations can be continued. By comparing the performance of different methods, a better method for signal adaptability can be obtained.
Keywords: Random vibration fatigue, Damage cumulative calculation, and Gaussian random vibration.

References:

Y. WANG, R. SERRA *Life assessment of structures using random vibration testing*, ENVIRORISK Bourges 3ème edition June 2018

R. SERRA, L. KHALIJ et al. *Effects de l'environnement vibratoire sur la durée de vie d'une éprouvette en aluminum.* SF2M, 35èmes Journées de Printemps, Mai 2016.

*Speaker

Helicopter transmission gearbox fault detection using an enhanced minimum entropy deconvolution adjusted method

Xin Zhang * [1,2], Jiaxu Wang [1], Zhiwen Liu [1], Jérôme Antoni [2]

[1] School of Aeronautics and Astronautics, Sichuan University – China
[2] Univ Lyon, INSA-Lyon – Laboratoire Vibrations Acoustique – France

Blind deconvolution (BD) has a very successful application on impulse extracting from amplitude anomalies in vibration recordings for machinery health monitoring and diagnostics. In this paper, we investigate the effect of an exponential transformation on the improvement of the performance of the minimum entropy deconvolution adjusted (MEDA) method for the extracting of periodic fault impulse trains. Meanwhile, based on the exponential transformation, a new varimax norm is defined as criterion for BD. The modified MEDA method is compared to the classical minimum entropy deconvolution (MED), the MEDA, the optimal minimum entropy deconvolution adjusted (OMEDA) on both simulated and experimental signals. The experimental data is from the seeded fault test of H-60 helicopter transmission gearbox. The results show that the modified MEDA performs considerably better than other comparison methods in the extracting of periodic fault impulse trains especially for incipient faults.
Keywords: Fault detection; helicopter gearbox; blind deconvolution; minimum entropy deconvolution adjusted; exponential transformation

References:

Buzzoni, Marco, Jérôme Antoni, and Gianluca D'Elia. "Blind deconvolution based on cyclostationarity maximization and its application to fault identification." Journal of Sound and Vibration 432 (2018): 569-601.

McDonald, Geoff L., Qing Zhao, and Ming J. Zuo. "Maximum correlated Kurtosis deconvolution and application on gear tooth chip fault detection." Mechanical Systems and Signal Processing 33 (2012): 237-255.

Ooe, M., and T. J. Ulrych. "Minimum entropy deconvolution with an exponential transformation." Geophysical Prospecting 27.2 (1979): 458-473.

McDonald, Geoff L., and Qing Zhao. "Multipoint optimal minimum entropy deconvolution and convolution fix: Application to vibration fault detection." Mechanical Systems and Signal Processing 82 (2017): 461-477.

*Speaker

Fault diagnosis and prognosis for rolling bearings

A non-parametric generalization of the synchronous average in the cyclo-non-stationary framework

Dany Abboud [1], Amadou Assoumane * [1], Yosra Marnissi [1], Mohammed El Badaoui [1,2]

[1] Safran Group – Safran Tech - Safran Group – France
[2] University of Lyon, University of Saint Etienne (LASPI) – LASPI – 20 Ave de Paris, 42334 Roanne, France

Deterministic-random separation is crucial in machine signal processing. It offers a way to remove the deterministic part and helps in eliminating the interference of the latter in the higher-order analysis of the random part. The most common example is the vibration signal of a power transmission chain comprising a gear and a bearing. In this context, the synchronous average is a widely used tool that separates the deterministic contribution from the random one. This tool consists on averaging the cycles of the vibration signal. In fact, it uses the cyclo-ergodicity hypothesis that assumes that, for a given location in the cycle, the associated samples share the same probability density function. This makes it possible to estimate the signal mean through the synchronous average, i.e. by averaging the samples associated with each position in the cycle. Once the synchronous average is performed, a differential diagnosis of the gears and the bearings can be unambiguously made. However, in many practical applications, the cycle-to-cycle statistics can change according to many factors such as the speed, torque, load, etc. The resulting signal is widely referred in the literature as cyclo-non-stationary. This jeopardizes the cyclo-ergodicity of the signal and, in consequence, the efficiency of the synchronous average. This paper addresses this issue by proposing a new non-parametric generalization of the synchronous average. The proposed method takes advantage of the smoothness of the probability function (in particular the mean) variation with respect to cycles. Instead of computing the mean of the samples located at a given angular location, it proposes to optimally fit the data with an appropriate curve. An efficient way to do this is the use of the Savitzky–Golay filter that smooths the data, for a given position in the cycle, without distorting the general tendency. This is achieved by fitting sub-sets of adjacent data points (of pre-defined width) with a low-degree polynomial by the linear least squares method. In this paper, the theoretical basics of this technique is provided and its efficiency is demonstrated on real vibration signals acquired under nonstationary operating conditions.

*Speaker

High Frequency Demodulation Technique for Instantaneous Angular Speed Estimation

Frédéric Bonnardot * [1], Khalid Lizoul *

[1], Saad Errafik [1], Hugo André [1], François Guillet [1]

[1] Laboratoire dÁnalyse des Signaux et des Processus Industriels – Université Jean Monnet [Saint-Etienne] : EA3059 – France

Many vibration monitoring methods use an accelerometer sensor in order to diagnose the systems. Instantaneous Angular Speed (IAS) has appeared to provide a new source of information on the rotating machine and it is commonly used to diagnose faults such as bearings faults [1], gearboxes [2], ...
Classically, IAS use an optical encoder as a speed sensor. This sensor is available in many rotating machines (especially for speed and position control). It provides a square / sine wave with a frequency proportional to the rotation speed. Thus, this signal is frequency modulated by the system speed variations. There are two major methods for recording IAS signal: timer / counter technics [3], and ADC- based methods [4]. The latter is limited by the capability of the ADC-board to collect the data (sampling frequency) which could restrict the use of higher encoder resolution and introduces spatial aliasing.

In this study, we are interested in IAS estimation using a super-heterodyne like demodulation technique. The idea is to be able to acquire the speed signal with relatively higher resolution without using a higher sampling frequency. The IAS signal is first analogously shifted in frequency domain in order to be acquired at a lower sampling rate. Then, the sampled signal is further treated to get IAS.

A first part recalls the classic IAS estimation methods and their limits. In a second part, a new technique is introduced for IAS estimation. The spectral components of the method are compared to the spectrum of the IAS signal estimated by elapsed time technique. At the end, the effect of noise is shortly discussed.

L. Renaudin, F. Bonnardot, O. Musy, J.B. Doray, and D. Rémond. Natural roller bearing fault detection by angular measurement of true instantaneous angular speed. Mechanical Systems and Signal Processing, 24(7):1998 – 2011, 2010. Special Issue: ISMA 2010.

Ming Zhao, Xiaodong Jia, Jing Lin, Yaguo Lei, and Jay Lee. Instantaneous speed jitter detection via encoder signal and its application for the diagnosis of planetary gearbox. Mechanical Systems and Signal Processing, 98:16 – 31, 2018.

*Speaker

H. André, F. Girardin, A. Bourdon, J. Antoni, and D. Rémond. Precision of the ias monitoring system based on the elapsed time method in the spectral domain. Mechanical Systems and Signal Processing, 44(1):14 – 30, 2014. Special Issue on Instantaneous Angular Speed (IAS) Processing and Angular Applications.

K. Lizoul, H. André, and F. Guillet. Improvement of instantaneous angular speed estimation based on frequency demodulation method under non stationary conditions. In Proceedings of ISMA2018 and USD2018, Leuven, 17-19 September 2018.

Heidenhain. Rotary Encoders brochure, 2018.

M. El Badaoui and F. Bonnardot. Impact of the non-uniform angular sampling on mechanical signals. Mechanical Systems and Signal Processing, 44(1-2):199–210, February 2014.

F. Bonnardot and J. Al Fallah. Non-uniform (re)sampling for optical encoder. In First World Congress on Condition Monitoring (WCCM), London, 13-16 June 2017.

Development of a vibration monitoring strategy based on cyclostationary analysis for the predictive maintenance of helicopter gearbox bearings

Valerio Camerini * [1], Lucas Macchi [1], Frederic Champavier [1], Gianni Naccarato [1]

[1] Airbus [France] – Airbus – France

The scope of this paper is the development of a fault detection and diagnosis method aimed to helicopter gearbox bearings vibration monitoring in an operational context. Bearings are critical components in the gearbox, and their monitoring allows for failure anticipation capabilities, leading to increased safety and improved maintenance planning. Deploying a monitoring strategy for helicopter gearboxes necessitates the development of a methodology which can provide reliable information under varying operating conditions, dealing with a noisy vibration environment and simultaneously considering acquisition system constraints, such as limited acquisitions and sampling frequency, and operational needs, such as low rate of false alarms and minimal workload for the analyst. The approach proposed in this paper is based on the cyclostationary signals theory and relies on a two-steps procedure of detection and diagnosis. First, bearing fault detection indicators are devised on a statistical basis, leveraging on the theoretical properties of the envelope method. Different indicators based on the squared envelope spectrum and on the recently proposed logarithmic envelope spectrum are obtained, with the aim of providing early warning to impending bearing faults, while keeping a low, predictable false alarm rate. Interfering signals from other rotating equipment within the gearbox are considered, as well as different noise statistics. Mitigation measures based on deterministic-random separation methods are considered. A detailed, original analysis of the effects of angular resampling on the statistics of envelope-based indicators is also carried out. In the second, diagnostic stage of the proposed approach, the averaged cyclic periodogram is computed to assess the damage in the eventuality of an alarm. The fault signal is then filtered out, allowing the analyst to take an informed decision on whether validating or rejecting the alarm. This allows minimizing the risks of a wrong maintenance decision. The developed methodology is validated on real helicopter data collected over about twenty thousand flight hours, including four bearings from different machines for which in-service spalling initiation occurred. Where a consistent amount of literature is available concerning the analysis of vibration detection methods on experimental rigs, there is a lack of comprehensive analyses based on operational helicopters data. A first contribution of the paper is in addressing this gap by investigating different envelope-based indicators in an industrial set-up, taking into account the associated complexities and uncertainties in a rigorous manner. The effect of interfering, periodic gear signals on the computed statistical indicators is considered, as well as that of the computed order tracking for angular resampling,

*Speaker

and of deviations from the white noise assumption. Further, the variability of the operating conditions across different acquisitions is taken into account, with considerations on the effect of rotating speed and torque level. It is shown that a proper statistical treatment allows obtaining predictable false alarm rates in the detection phase across all the encountered flight conditions, maintaining the capability of providing early warning in case of fault development. On a second level, the proposed combined detection and diagnosis strategy is demonstrated on a variety of cases, proving the robustness of the approach and validating its applicability within an operational framework. The detection performance is assessed on the basis of the achieved false alarm rates and the improvement in fault anticipation with respect to chip detectors, whereas the capabilities of isolating the fault-related signals using cyclostationary signal separation methods is shown for the diagnosis stage.

A new indicator designed from the spectral coherence, proposition and application to bearing diagnosis

Souhayb Kass * [2,1], Amani Raad *

[3], Jérôme Antoni *

1

[2] Doctoral School of Science and Technology, Lebanese University, Tripoli, Lebanon – Lebanon
[1] Laboratoire Vibrations Acoustique, Univ Lyon, INSA-Lyon, LVA EA677, F-69621 Villeurbanne, France – INSA Lyon – France
[3] Engineering faculty, Lebanese University, Tripoli, Lebanon – Lebanon

In the vibration-based diagnosis of rolling element bearings, the complexity of the signals requires an expert to use advanced signal processing tools and to interpret the results based on his/her experience. Recently, a few autonomous methods have been proposed to alleviate the demand on the user's expertise, yet they have been mainly focused on fault detection. They ideally track certain properties in the signal, whose occurrence is correlated with the symptom of a fault. This paper follows a similar direction but with wider objectives: it aims to develop an indicator that is sensitive to both non-stationarity, non-Gaussianity and to the modification of the acoustic signature of the vibratory signal. The indicator is based on the recently developed Fast Spectral Coherence, a key tool of the theory of second-order cyclostationary processes. It condenses the whole information initially displayed in three dimensions into a scalar. it initially addresses the case where the faults frequencies are unknown. In addition, the proposed indicator is able to return information for different levels of damages in both stationary and non-stationary operating conditions. A new pre-processing step is provided to ensure an efficient and constant statistical threshold. The proposed indicator is intended to be used in an autonomous process without the need for visual analysis and human interpretation. The proposed indicator is compared with a recent indicator based on the Envelop Spectrum, in terms of classification and detection performance. Several applications using real and benchmarked data eventually illustrate the capability for self-running diagnosis.

*Speaker

Multi band integration on the cyclostationary bivariable methods for bearing diagnostics.

Alexandre Mauricio * [1,2], Konstantinos Gryllias [2,3]

[1] KU Leuven, Faculty of Engineering Science, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300 B, B-3001, Heverlee, Belgium – Belgium
[2] Dynamics of Mechanical and Mechatronic Systems, Flanders Make – Belgium
[3] KU Leuven, Faculty of Engineering Science, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300 B, B-3001, Heverlee, Belgium – Belgium

Rolling element bearings are critical parts of rotating machinery, as they support the loads applied to the rotating components. Therefore, continuous monitoring of the health state of the operational bearings is applied in order to detect early damages before any unexpected breakdown of the rotating machinery occurs. Bearing diagnostics is a field of intensive research, focusing nowadays mainly in complicated machinery (e.g. planetary gearboxes, multi-stage gearboxes, etc.) operating under varying conditions (e.g. varying speed and load), as they still provide challenges in terms of accuracy and time of detection/diagnosis.
One of the most common methods for bearings diagnostics is the Envelope Analysis. A filter is usually applied around an excited frequency band (by impulsive damage) and the signal is enveloped, thus obtaining the Squared Envelope Spectrum. For the detection of the filtering frequency band, several band selection tools have been proposed in the past that extract the optimal band in a semi-autonomous or fully autonomous manner. The most widely used tool for band selection is the Kurtogram, where the band that returns the highest Spectral Kurtosis value is selected as the optimal band for demodulation [1]. However, as the bearing damage may excite several frequency bands simultaneously, band-pass filtering around only one frequency band may not be sufficient for the detection of the bearing fault under the presence of noise. One proposed method to circumvent this case is to filter around several bands that carry the Signal of Interest (bearing damage signature). Recently, multi-band filtering based on the Autogram feature values, used as a pre-step in order to extract the Combined Squared Envelope Spectrum (CSES) has been presented, providing better detection performance of faulty bearings compared to the extraction of the SES after filtering over a single optimal band returned by the Autogram [2].

Recently, a particular interest had been target to the Cyclic Spectral Correlation (CSC) and to the derived methods, due to their effectiveness in describing second-order cyclostationary signals. One of such methods is the Cyclic Spectral Coherence (CSCoh) which is a normalized version of the CSC bivariable map [3]. Both methods are represented in the frequency-frequency domain. It has been shown that the integration of the bivariable functions over discrete spectral frequency bands is analogous to band-pass filtering. The IESFOgram has been proposed [4] as a band selection tool, based on either the CSC or CSCoh, in order to extract the optimal

*Speaker

frequency band. The integration on the frequency band of the bivariable map further enhances the detectability of faulty bearings on the resulting Improved Envelope Spectrum (IES). However, the method has been proposed with the integration of one single band. In this paper the method is extended towards the extraction of the Combined Improved Envelope Spectrum (CIES), performing a multi-band integration of the bivariable map around multiple resonant frequencies that are carriers of the bearing damage signature. The proposed method is applied, tested and evaluated on experimental data and the results are compared with other state-of-the-art band-selection tools.

Antoni, J., Fast computation of the kurtogram for the detection of transient faults. *Mechanical Systems and Signal Processing*, 21, pp. 108-124 (2007).

Moshrefzadeh, A., Fasana, A., The Autogram: An effective approach for selecting the optimal demodulation band in rolling element bearings diagnosis. *Mechanical Systems and Signal Processing*, 15, pp. 294-318 (2018).

Antoni, J., Abboud, D., Xin, G.,, Cyclostationarity in Condition Monitoring: 10 years after. *Proceedings of ISMA 2016 including USD 2016*, Leuven, Belgium, (2016).

Mauricio, A., Smith, W., Qi, J., Randall, R., Gryllias, K., Cyclo-non-stationarity based bearings diagnostics of planetary bearings. *International Conference on Condition Monitoring of Machinery under non-stationary conditions of CMMNO 2018*, Santander, Spain, (2018).

Data Mining Classification & Machine Learning methods

A Deep Learning Protocol for Condition Monitoring and Fault Identification in a Rotor-Bearing System from raw Time-Domain data

Nikhil Sonkul [1], Jasdeep Singh [1], Nalinaksh S. Vyas * [1]

[1] Indian Institute of Technology Kanpur – India

A Deep Learning protocol is developed for identification of typical faults ocurring in rotating machinery. In past Support Vector Machines (SVMs), Clustering, Artificial Neural Networks (ANNs) and other algorithms have been used for this purpose [1]. Conventional Back-Propagation ANNs [2-4] have adequately performed fault recognition. However they mostly require that the raw time-domain data, from the sensors on the machine, be first processed and handcrafted parameters like Fast Fourier Transform (FFT) coefficients, Statistical Moments etc be fed as inputs. These methods are inadequate to fulfil the required task with raw sensor response as inputs. This failure is due to the fact that conventional Back-Propagation ANNs suffer from the vanishing gradient problem. While back-propagating the error in such networks, the weight updation, primarily, gets done at layers encountering the backward motion first. The layers at the extreme end gradually become insensitive to inputs as the back-propagated error gradient vanishes by the time it reaches them. And therefore, such networks requre that raw data be a-priori processed suitably, to handcraft information rich inputs to initial layers.

Deep Learning can be understood as a form of neural network with a large number of layers. Convolution Neural Network (CNN) architecture is commonly used in deep networks used for image recognition [5]. CNNs comprise identical copies of the same neuron. Rectified Linear Unit (ReLU) is a popular function defining a neuron in such architecture. Repeatative weights called kernels, which remain common for all neurons in a layer, can be learnt from raw data.

Deep Learning has been applied to Machine Condition Monitoring also [6,7], with elementary pre-processing of raw data. In this study, a Deep Learning CNN architecture has been developed, employing the analogy of an RGB coloured image, to directly work upon the raw time-domain signals obtained from sensors on a rotor-bearing system. The analogous RGB channels, are vibration data from different sub-systems of the complete rotor-bearing assembly. (i) Bearing Sensors (ii) Shaft Sensors (iii) Gear Sensors form the three sub-systems, in this study.

Data from an earlier investigation by the author on a Machinery Fault Simulator rig is used. The rig includes two rotors mounted on the shaft, driven by a DC motor, whose operating speed, acceleration etc can be controlled. The rotor disc can be mounted on the shaft at desired location. A flexible coupling is used to connect rotor shaft to that of motor to compensate for any misalignment between the bearings as well as preventing any unwanted dynamic effects

*Speaker

occurring in the motor being transmitted through the coupling into the rotor itself. At one end of the shaft there is a sheave which is connected to a reciprocating mechanism through a belt drive and a gear-box. Two sensors each are used on the individual sub-systems. Data from upto twenty faults were used. The faults included – Unbalance, Eccentric Rotor, Cocked rotor, Bearing Outer Race Defect, Bearing Inner Race Defect, Ball Spin Fault, Loose Belt, Tight belt, Missing Tooth, Loose Gear etc.

The Deep Learning Network effectively recognizes all twelve kinds of faults that were investigated. The accuracy is identical to that obtained from conventional back-propagation method implemented on the same set of data, but which required FFTs or Statistical moments as inputs.

This study illustrates this usage and comparison.

References

Jardine, A. K. S., Lin, D., & Banjevic, D. (2006). "A review on machinery diagnostics and prognostics implementing condition-based maintenance". Mechanical Systems and Signal Processing. *Vyas N.S., Satishkumar D. (2000).* "Artificial Neural Network Design for Fault Identification in a Rotor-Bearing System", Mechanism and Machine Theory, Vol 36(2), pp. 177-188. *Vyas N.S., Jain N, Pandey S. (2002).* "Fault Identification in Rotating Machinery Using Neural Networks", Advances in Vibration Engineering, Vol.1, No.1, 2002, pp. 90-99. *Singh Jasdeep, 2006.* "Condition Monitoring of Geared Rotor Systems Using Neural Networks", M.Tech. Thesis, IIT Kanpur. *Ian Goodfellow, Bengio, Y., & Courville, A.* (2017). "Deep learning". Nature Methods (Vol. 13, p. 35). *Zhao, R. et al.* (2016), "Deep Learning and Its Applications to Machine Health Monitoring: A Survey", 14(8), pp. 1–14. doi: 10.1016/j.jocs.2017.06.006 *Sadoughi, Mohammakazem; Downey, Austin; Bunge, Garrett; Ranawat, Aditya; Hu, Chao; and Laflamme, Simon,* "A Deep Learning-based Approach for Fault Diagnosis of Roller Element Bearings" (2018). Civil, Construction and Environmental Engineering Conference Presentations and Proceedings. 97.

Gears faults classification: from mastered data to new ones using transfer learning.

Alexandre Carbonelli * [1], Valentin Baron [2], Sylvain Barcet [3]

[1] VIBRATEC (VIBRATEC) – vibratec – 28 CHEMIN DU PETIT BOIS, 6930 ECULLY, France
[2] MicrodB – MicrodB, 28 Chemin du petit bois, 69130 Ecully – France
[3] Vibratec – vibratec – France

Gears are used in a huge quantity of mechanical systems. As a consequence, monitoring their possible faults the most accurately possible, is a major issue in the field of Structural Health Monitoring (SHM) as they can end provoke critical damages. With the increasing use of machine learning techniques to deal with this problem, progress on features to use for classification of certain types of defaults is made. Nevertheless from a supervised machine learning point of view, it can sometimes be really difficult to have access to ground truth labels for a given database. The goal of this work is to use transfer learning techniques in order to go from a mastered dataset to a new one in order to classify faults that are well known in the former case. Indeed by first applying known faults on a controlled test bench, a supervised machine learning model is learned with labels corresponding directly to the faults introduced. Then by using transfer learning techniques on data produced by another bench, these new data are transferred into the space spanned by the known case and a classification in this space using the model previously learned is performed to make a correspondence between the implemented faults and the ones from the new database. Results show that some of these faults are actually combined whereas unknown cases emerge corresponding to new defaults not implemented in the controlled test bench. These specific cases are classified in a separated class for further investigations. This work brings another contribution to the understanding of engineered features in the context of geared systems health monitoring and let us glimpse the opportunity of a global understanding of a system, iteratively, thanks to each new study that is providing new data.

*Speaker

WIND TURBINE GEARBOXES FAULT DETECTION THROUGH ON-SITE MEASUREMENTS AND VIBRATION SIGNAL PROCESSING

Francesco Castellani * [1], Davide Astolfi [1], Luigi Garibaldi [2], Alessandro Paolo Daga [2]

[1] University of Perugia – Italy
[2] Politecnico di Torino – Italy

Condition monitoring of wind turbine gearboxes has attracted an impressive amount of attention in the wind energy literature. This happens on one side for practical issues: it is estimated that wind turbines unavailability time is of the order of the 3% of the lifetime and that gearbox damages account for at least the 20% of it. On the other side, the condition monitoring of gear-based mechanical systems undergoing non-stationary operation is scientifically challenging.
On these grounds, the present work is devoted to the diagnosis of gearbox damages through a novel approach, designed exclusively for this study, based on on-site measurements and data post-processing. The main point of this method is the relatively easy repeatability, also for wind turbine practitioners, and its low impact on wind turbine operation: actually, the measuring site is not the gearbox, but it is instead the tower. Longitudinal and transversal accelerations are measured inside the tower at 7 and 2 meters above the ground.

A real test case has been considered: a multi mega-watt wind turbine sited in Italy and owned by the Renvico company (www.renvicoenergy.com). Measurements have been collected at the target wind turbine, where the fault was supposed occurring (on the grounds of oil particle counting analysis), and at a two reference wind turbines, that were supposed to be healthy. The data have been subsequently processed through a multivariate Novelty Detection algorithm in the feature space. The application of this algorithm is justified by univariate statistical tests on the selected time-domain features and by a visual inspection of the dataset via Principal Component Analysis.

The main result of this work is that the novelty index based on time-domain features (as for example the Mahalanobis distance), computed from the accelerometric signals acquired inside the turbine tower, proves to be suitable to highlight a damaged condition in the wind-turbine gearbox, which can be then successfully monitored.
This system is non-invasive with respect to wind turbine operation and the results of this study support that it can, in principle, enable to monitor also the damage evolution in time, establishing the foundations for further works on prognostics, which could optimize the wind turbines maintenance regimes, ensuring higher reliability and minimal down times.

*Speaker

Gears and bearings defaults: from classification to diagnosis using machine learning

Sylvain Barcet * [1], Alexandre Carbonelli [2], Valentin Baron

[1] Vibratec – Vibratec, vibratec – France
[2] VIBRATEC (VIBRATEC) – vibratec – 28 CHEMIN DU PETIT BOIS, 6930 ECULLY, France

Gears and bearings are more and more used in every industrial area mainly due to their strong reliability. Nevertheless as every mechanical transmission system, failures appear during time life. It induces critical damage, time cost for maintenance services to repair the fault potentially on duty. A wide part of work in the scientific community already provides a large quantity of features to follow health status of these systems (e.g., RMS, kurtosis, crest factor, FM0) in order to detect the fault as soon as possible.

Since few years, methods developed in signal post-processing are coupled with Machine Learning (ML). ML allows ability to detect novelty or fault based on a trained algorithm. According to the literature [1], to identify the type of damage, a supervised algorithm is needed. Consequently an accurate diagnosis implies labelled data which are often difficult to obtain practically.

The aim of this paper is to provide keys, based on our knowledge about features in Structural Health Monitoring (SHM), to get higher information level in classification by adding a qualitative analysis (type of damage) without label or information about the type of fault.

Work carries on a measurement database. The assumption is made about two classes "healthy" / "faulty" using a supervised algorithm. The contribution of our work brings a new step in the default analysis by adding a probability for a defect case to be identified. Indeed, by combining some sensitive features selected for their relevance to describe a type of fault, a probability to have this particular default can be given. This classification is tested against three fault classes: bearing, gear generalized, gear localized.

Results show that a probability for having bearing fault can be identified using this method contrary to the gear generalized and localized fault which are more complex to characterize. This new step enables to help maintenance services to focus more efficiently on the incriminated faulty part of the system, inducing a reduction of time to repair for maintenance services, a shorter out of order time leading to a significant productivity gain.

*Speaker

Vibration Feature for Detecting Eccentric Workpiece/Runout Faults During Continuous Gear Grinding Processes

Agusmian Partogi Ompusunggu * [1], Yann Vonderscher [2], Daniel Motl [2]

[1] Flanders Make vzw – Belgium
[2] VCST Industrial Products – Belgium

Continuous gear grinding is a well-established and widely used process in the industry for large-scale production gears. It offers an economic/efficient process for finishing gears, which shapes the micro-geometry of the gear tooth flank and improves its surface quality. The resulting quality of ground gears depends on several factors, namely the tool performance, the machine stability as well as the correct clamping/positioning of the workpiece. The grinding step is very crucial since it has a direct impact on the operating quality of gears and in particular on the running noise behaviour of the end product.
The potential of online vibration based gear grinding monitoring has been explored and demonstrated in the previous work [1] as a means of quality control that could lead to the overall reduction of production losses and to the prevention of sending defective parts to customers. A number of features which could be used to monitor the grinding processes and to identify a specific type of defects have been proposed & experimentally validated to some extent. The types of faults include i) high feed rate, ii) high infeed, iii) non-flat workpiece, and iv) eccentric workpiece. However, a further investigation on a new test campaign revealed that none of the features developed in [1] was sensitive and robust enough to detect eccentric workpieces during the grinding process. It is worth mentioning here that an eccentric workpiece fault is unlikely to happen, but it is analogous to a runout on the incoming workpiece quality.
In this paper, a qualitative model to predict the vibration signature due to eccentric workpieces/runouts is developed and discussed. Based on the qualitative understanding, a novel feature to detect eccentric workpieces/runouts during gear grinding processes based on vibration signals has been developed. The newly developed feature has been validated on real vibration signals captured during the emulation of process malfunctions on an industrial gear grinding machine. The experimental results show that the novel feature is sensitive and robust for detecting workpiece eccentricities of about 40 microns. It is also shown in this study that the feature is insensitive to other types of gear grinding faults, which is important for diagnostics/root-cause analysis purposes.

*Speaker

Toward the quality prognostic of an aircraft engine workpiece in Inconel Alloy 625: case study and proposed system architecture

Antoine Proteau * [1], Souheil-Antoine Tahan [2], Marc Thomas [3]

[1] Ecole de Technologie Supérieure [Montréal] – Canada
[2] Ecole de Technologie Supérieure (ETS) – 1100, rue Notre-Dame Ouest Montréal (Qc) H3C 1K3 Canada, Canada
[3] École de technologie Superieure (ETS) – 1100 Notre Dame West, Montréal, H3C1K3, Québec,, Canada

Manufacturing companies are under a constant pressure due to multiple factors: new competition, disruptive innovations, cost reduction request, etc. To survive, they must strive to innovate and adapt their business model to improve their productivity. Recent developments based on the concept of Industry 4.0 such as big data, new communication protocols and artificial intelligence provide several new avenues to explore. In the specific context of machining, we are working toward the development of a system capable of making the prognostic of the quality (in terms of dimensional conformance) of a workpiece in real time while it is being manufactured. The goal of this paper is to showcase a prototype of the data acquisition aspect of this system and a case study presenting our first results. This case study has been conducted at our industrial partner facility (Quebec, Canada) and is based on the manufacturing of an aircraft component made from Inconel alloy 625 (AMS5666). The proposed prototype is a data acquisition system installed on a 5 axis CNC machines (GROB model G352) used to acquire and to contextualize the vibration signal obtained from the CNC machine sensor. The contextualization of the data is a key component for future work regarding the development of a prognostic system based on supervised machine learning algorithms. In the end, this paper depicts the system architecture as well as its interactions between the multiple systems and software already in place at our industrial partner. This paper also shows preliminary results describing the relationship between the workpiece quality (in terms of respect toward the dimensional requirements) and the extracted features from the sensors signals. We conclude that it is now possible to do the diagnostic of a cutting operation. Additionally, with the same information we show that it is possible to quickly do the general diagnostic of the health state of the machine. Future work regarding this project will include data acquisition from a wider range of products (i.e. different shapes, materials, processes, etc.) and the development of a machine learning based prognostic model.

*Speaker

A Deep Learning-based Approach for fault diagnosis: Application to Bearing Fault Detection

Khalid Dahi * [1]

[1] Ecole Centrale Casablanca – Morocco

Bearing faults are the most common problems in rotating machinery, which can be catastrophic and cause significant downtime. Therefore, it is essential to provide an early warning and accurate fault detection in such components. Over the past few years, deep learning techniques (DL), especially convolutional neural network (CNN), has been recognized as a useful tool for fault detection of bearing fault. Unlike the traditional fault diagnosis approaches, deep learning methods does not require manually extracting the fault-related features from the raw sensor data. The proposed approach presented in this paper has two main steps: the first step is to perform preprocessing for each sensor signal acquired from a bearing to maximize the signal-to-noise ratio without losing the critical diagnostic information carried by the signal; and the second step is to introduce these signals into the CNN algorithm which classifies the rolling state into healthy or faulty states. The performance of the proposed algorithm was examined through real data from a test to failure bearing. Finally, the fault detection method is compared with Support Vector Machine (SVM) which is one of the most used techniques for fault diagnosis in the literature to investigate the sensitivity and accuracy of this technique.

*Speaker

Fault prognosis of planetary gearbox using acoustic emission and genetic algorithm: a case study

Felix Leaman * [1], Cristián Molina Vicuna [2], Ralph Baltes [1], Elisabeth Clausen [1]

[1] RWTH Aachen University – Germany
[2] Laboratorio de Vibraciones Mecánicas, Universidad de Concepción (LVM-UdeC) – Edmundo Larenas 219 (of.336), Barrio Universitario, Concepción, Chile

One of the most important aspects of machine fault prognosis is the selection of sensors and features to represent the degradation process of a faulty component. Several approaches in the literature have used features extracted from vibration signals to estimate the future condition based on time series forecasting. Another technology that has been used increasingly for this task are the acoustic emission (AE) sensors, which have frequency measurement ranges much higher than vibration sensors. On gearboxes some studies have shown that the AE technology can be used effectively for fault diagnosis, but its use for fault prognosis is still a relative new field of research that offers encouraging opportunities. One downside of the application of the AE technology in gearboxes is the strong dependence of the AE on the oil temperature, which may lead to difficulties during the forecasting of an AE-based feature. Thus, in this study a novel feature based on a relative counting of the AE bursts is proposed and tested with data from a planetary gearbox with a ring gear fault. The proposed feature reduces the influence of the temperature on the generation of AE when it is compared to the counting based on a fixed amplitude threshold. Therefore, it can then be more suitable for fault prognosis than traditional AE counting. In this case study the forecasting of the proposed feature is carried out using an artificial neural network (ANN), whose hyperparameters were selected using a genetic algorithm. The results are promising and constitute a basis for further research.

*Speaker

Rotating machine diagnosis using acoustic imaging and artificial intelligence

Abdelhakim Darraz * , Jean-Hugh Thomas [1], Pierre Mollon [2], Gabriel Kirie [2], Jérôme Antoni [3], Anthony Larcher [4]

[1] Laboratoire d'Acoustique de l'Université du Maine (LAUM) – Université du Maine – rue Olivier Messiaen 72085 Le Mans cedex 9, France
[2] VALEO – Valeo Equipements Electriques Moteur – France
[3] Laboratoire Vibrations Acoustique (LVA) – Institut National des Sciences Appliquées de Lyon – Bâtiment St. Exupéry, INSA Lyon, 25 bis, avenue Jean Capelle 69621 VILLEURBANNE CEDEX, France
[4] Laboratoire dÍnformatique de lÚniversité du Mans (LIUM) – Le Mans Université : EA4023 – Avenue Laennec 72085 Le Mans cedex 9, France

Mass production of quality equipment in the automotive industry requires controls throughout the production line. These controls are done through monitoring and validation tools for both production and finished products. The use of signal processing methods, applied to acoustic and vibratory recordings collected during the operating cycle, aims to ensure that they are in good working order, to maintain them and to guarantee the quality of the service provided by the manufacturer to its customers.
Sometimes the techniques used do not reach the expected performance, which of course depends on the defect to be recognized but also on the conditions under which the measurements were made. Indeed, in a production environment many parts are unfairly detected as defective when monitoring is based on indicators from the literature. The causes of these errors are often related to the not conducive noisy environment to such a diagnosis by indicators sensitive to disturbance. Moreover, from one production site to another, it is not possible to apply the same default detection thresholds because of a different environment involving a variation of the structures and product frequency responses. Therefore, today it remains difficult to do a relevant diagnosis in a noisy environment and particularly on non-stationary signals. The aim of the study is to improve this diagnosis by first using a microphone antenna and then operating an artificial intelligence process on a database acquired on production benches.

The microphone array leads to obtain a spatial map of the acoustic field generated by the monitored system. An acoustic imaging approach allows the addition of a new spatial dimension in the data representation. The preliminary study presented consists in differentiating several states of the system to be monitored from the simultaneous exploitation of information expressed in the time-frequency-space domain.
The system considered is an electric motor composed of several subassemblies such as planetary gear reducer, a drive shaft, an armature permitting under the effect of a magnetic field the rotation of the motor and a current transmission subassembly allowing the current to flow to the armature by brushes. Each subset radiates its own acoustic signal which, by interactions, contributes to the overall signal emitted by this motor. These interactions associated to the

*Speaker

resonance phenomena in the transient operating phases of the machine make the diagnosis more difficult. Using an antenna makes the diagnosis less sensitive to disturbance and thus more reliable. Indeed, this one allows to focus the acoustic measurement on the rotating machine by a beamforming process while freeing of the disturbing sources coming from other directions. First results of comparison will be presented.

Macroscopic-Microscopic Attention in LSTM Networks based on fusion Features for prediction of bearing remaining life

Yi Qin * [1,2], Sheng Xiang *

[1,2], Haoran Yan *

[1,2]

[1] College of Mechanical Engineering, Chongqing University, Chongqing 400044 – China
[2] State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 400044 – China

Abstract: In the mechanical transmission system, the bearing is one of the most widely used transmission components. The failure of the bearing will cause serious accident and huge economic loss. Therefore, the remaining life prediction of the bearing is greatly important. In order to predict the remaining life of the bearing, a prediction method combining macro-micro attention, long-short-term memory neural network and isometric mapping is proposed. First, some typical time-domain and frequency-domain characteristics of the vibration signal are calculated .respectively, such as the maximum value, the absolute mean value, the standard deviation, the kurtosis and so on. Then, the principal component of these characteristics is extracted by the isometric mapping method. The importance of fusional characteristic information is filtered via a proposed macro-micro attention mechanism, so that the input weight of neural network data and recursive data can reach multi-level real-time amplification. With the new long short-term memory neural network, the characteristic of the bearing vibration signal can be predicted based on the known fusional characteristic. The experimental results show that the method can predict the remaining life of the bearing well and has higher prediction accuracy than the conventional LSTMs. **Key words:** remaining life prediction; long short-term memory neural network; macro-micro attention mechanisms; vibration signal; feature fusion

*Speaker

Milling diagnosis using machine learning approaches

Dominique Knittel * [1,2], Mohammed Nouari [3]

[1] Laboratoire d'étude des microstructures et de mécanique des matériaux (LEM3) – LEM3 – 7 rue Félix Savart, 57073 Metz, France
[2] University of Strasbourg, Faculty of Physics and Engineering – Université de Strasbourg, université de Strasbourg – 3 rue de l'Université, 67000 Strasbourg, France
[3] Laboratoire dÉtude des Microstructures et de Mécanique des Matériaux (LEM3) – Université de Lorraine, Centre National de la Recherche Scientifique : UMR7239 – France

The Industry 4.0 framework needs new intelligent approaches. Thus, the manufacturing industries more and more pay close attention to artificial intelligence (AI). For example, smart monitoring and diagnosis, real time evaluation and optimization of the whole production and raw materials management can be improved by using machine learning and big data tools. An accurate milling process implies a high quality of the obtained material surface (roughness, flatness). With the involvement of AI-based algorithms, milling process is expected to be more accurate during complex operations.
In this work, a smart milling diagnosis has been developed for composite sandwich structures based on honey-comb core. The use of such material has grown considerably in recent years, especially in the aeronautic, aerospace, sporting and automotive industries. But the precise milling of such material presents many difficulties. The objective of this work is to develop a data-driven industrial surface quality diagnosis for the milling of honey-comb material, by using supervised machine learning methods. Therefore, cutting forces and workpiece material vibrations are online measured in order to predict the resulting surface flatness.

The workpiece material studied in this investigation is Nomex® honeycomb cores with thin cell walls. The Nomex® honeycomb machining presents several defects related to its composite nature (uncut fiber, tearing of the walls), the cutting conditions and to the alveolar geometry of the structure which causes vibration on the different components of the cutting effort.

Given the low level of cutting forces, the quality of the obtained machined surface allows to establish criteria for determining the machinability of the honeycomb structures. Nearly 40 features are calculated in time domain and frequency domain from the raw signal in steady state behavior (transient zones are not taken into account). The features are then normalized. The input parameters for each experiment are: the tool rotation speed, the cutting speed and the depth of cut. It is then necessary to make a dimensional reduction of that feature table in order to avoid overfitting and to reduce the computing time of the learning algorithm.

In this work, several classification algorithms have been implemented such as : k-nearest neighbor (kNN), Decision trees (DT), Support Vector Machine (SVM). The different supervised learning algorithms have been implemented and compared. Each AI-based model has been applied to

*Speaker

a set of features. From the prediction results, SVM algorithm seems to be the most efficient algorithm in this application.

Passive control of vibrations

Experimental identification of the corrective effect of a non-circular pulley : application to timing belt drive dynamics

Sébastien Passos * [2,1], Lionel Manin [2], Didier Remond [2], Olivier Sauvage [1], Laurent Rota [1], Etienne Besnier [2]

[2] LaMCoS – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621 – France
[1] Groupe PSA – Scientific and Future Technologies Department, OpenLab Vibro-Acoustic-Tribology @Lyon, F-78943 – France

Timing belt drives used in automotive engines are subjected to pulley angular vibrations and span tension fluctuations induced by various excitation sources such as fluctuating camshaft torque and crankshaft acyclism. Excessive vibrations and tension fluctuations can lead to undesirable phenomena such as noise, belt fatigue, desynchronization of engine components and overconsumption.
Faced to this issue, car manufacturers have recently introduced non-circular pulley profiles in timing belt drives. A non-circular pulley causes periodic elongations of its adjacent belt spans. Hence, the pulley behaves like a corrective exciter able to counteract the effect of the excitation sources acting on transmissions. It is now known that optimal pulley profile shape and phasing with respect to other pulleys can improve considerably the vibratory performances of the transmissions.

For determining the optimal values of these parameters and obtaining an efficient design of the belt transmissions, it is necessary to fully understand the key-phenomena related to the use of non-circular pulleys.

Previous experimental studies have provided a rigorous description of the proper effect of an oval pulley on the angular dynamics of an academic two pulley transmission with no excitation source (no acyclism on the driving pulley rotation and constant load torque on the driven pulley).

Following these works, the present paper aims at showing experimentally how an oval pulley can generate a corrective effect able to counteract an excitation source such as a fluctuating load torque. For that purpose, the oval pulley is mounted on the driving axis of a transmission whose architecture is similar to that of a 4-cylinder car engine timing belt drive. It comprises one driving pulley (crankshaft), one driven pulley subjected to a second order periodic load torque (camshaft) and two idler pulleys located on each span.

The experiments are carried out following a wide experimental plan: large speed-range and various pulley phasing. The test-bench used for the experiments delivers a complete vibrational diagnosis of the transmission thanks to a very efficient instrumentation providing the measure of:

*Speaker

- the pulleys' rotation (optical encoders) and torques (torque-meters),

- the transverse vibrations of the belt spans (laser distance sensor),

- the belt span tensions thanks to idler supports instrumented with strain gages.

The results obtained from the experiments are analyzed in the angular and angular frequency domains. The study points out the corrective effect of the oval pulley by showing how the different tested phasing values influence the level of angular vibrations and tension fluctuations in the transmission.
Keywords: timing belt, non-circular pulley, angular vibrations, vibration reduction, experiments.

Robust optimization of nonlinear energy sinks used for dynamic instabilities mitigation of an uncertain friction system

Cherif Snoun * [1], Baptiste Bergeot [1], Sébastien Berger [1]

[1] Laboratoire de Mécanique Gabriel Lamé – Univ. Orléans, Univ. Tours, INSA CVL, Lamé, EA 7494, France – France

In this paper, robust optimization tool is proposed for nonlinear energy sinks used for the mitigation of friction-induced vibrations due to mode coupling instability in braking systems. The study is based on a mechanical system which is composed of two NESs coupled to the well-known two-degrees-of-freedom Hulten's model. ' In such an unstable system coupled with NES, it is usual to observe a discontinuity in the steady-state amplitude profiles which separates the parameters space into two parts which contain mitigated and unmitigated regimes respectively. We developed a methodology based on Multi-Element generalized Polynomial Chaos to identify this discontinuity which allows us to determine the Propensity of the system to undergo a Harmless Steady-State Regime (PHSSR). The objective of this work is, therefore, to maximize the value of PHSSR to obtain an optimal design of the NESs. For that, several stochastic optimization problems are presented taking into account the dispersion of the uncertain parameters
Keywords: Brake squeal noise, Harmful limit cycle oscillations, Nonlinear Energy Sink, Uncertainties, Multi-Element generalized Polynomial Chaos method, Robust optimization

References

Bergeot. B, Berger. S and Bellizzi. S, Mode coupling instability mitigation in friction systems by means of nonlinear energy sinks : numerical highlighting and local stability analysis, Journal of Vibration and Control, 24 (2017) 3487–3511.

Boroson. Ethan, Missoum. Samy, Mattei. Pierre-Olivier and Vergez. Christophe, Optimization under uncertainty of parallel nonlinear energy sinks, Journal of Sound and Vibration, 394 (2017) 451–464.

*Speaker

Energy exchange between a nonlinear absorber and a pendulum under parametric excitation

Gabriel Hurel * [1], Alireza Ture Savadkoohi [1], Claude-Henri Lamarque [1]

[1] Univ. Lyon, ENTPE, LTDS UMR CNRS 5513, rue Maurice Audin, 69518 Vaulx-en-Velin, France – École Nationale des Travaux Publics de l'État [ENTPE] – France

Keywords Pendulum, nonlinear absorber, parametric excitation

Introduction To reduce the oscillations of a pendulum type structure, Matsuhisa et al. [3] proposed a linear damper. Since then, nonlinear absorbers have been studied and developped as the nonlinear energy sink (NES) [4]. Hurel et al. [1] studied the behavior of a two degree-of-freedom pendulum coupled with a NES under a generalized force. Here we study the two dimensional model of the same system under a parametric excitation corresponding to the imposed vertical movement of the attached point of the pendulum.

Description of the system The main system is a pendulum of masses M in the gravitational field which can oscillate in the plan around its attachment point O with an angle phi. A nonlinear absorber is coupled to the pendulum at a distance a from O. The absorber is a mass m $<<$ M linked to the pendulum with a purely nonlinear cubic restoring force and a damping. The relative displacement of the mass is in the orthogonal direction of the main axis of the pendulum. The displacement of the point O in the vertical direction is imposed and is assumed to be periodic. It is expressed with Fourier series. The governing equations of the system are determined with the Lagrange equations.

Analytic development The system is treated with a multiple scales method where the small parameter epsilon is the ratio of mass m and M. We assume the variables are very small and we perform a rescaling with epsilon. Then, the complex variables of Manevitch are introduced Phi and U [2]. The different time scales are linked to each other with the parameter epsilon. A Galerkin method is used to keep only the first harmonic of the response of the system. We assume that the fundamental frequency of excitation is close to the natural frequency of the pendulum. At the first time scale, the system equations describe an asymptotic state called slow invariant manifold (SIM) with its stable and unstable zones. At the second time scale, the equations show that the amplitude of oscillations depends on the second coefficient of the Fourrier series. For a given value of this coefficient, the equilibrium and singular points can be represented as a function of the frequency of excitation. For some frequencies, several equilibrium points exist. To better understand the behavior of the system, we need to trace the phase portrait of the variable Phi. The analysis of the basins of attraction identifies the domain where the amplitudes are decreasing to zero and the domain where the oscillation are maintained.

*Speaker

Numerical integrations In order to validate the analytic developments, the governing equations of the system are numerically solved.

Conclusion First, the analytic study is coherent with the numerical results and it gives us keys to understand the behavior of the system. This study shows that there are possibilities of multiple states of equilibrium (stable or unstable) which should be traced carefully in design.

References

Hurel, G., Ture Savadkoohi, A., Lamarque, C.H.: Nonlinear vibratory energy exchanges between a two degrees-of-freedom pendulum and a nonlinear absorber. Journal of Engineering Mechanics (2018). DOI 10.1061/(ASCE)EM.1943-7889.0001620. (in press)

Manevitch, L.I.: The Description of Localized Normal Modes in a Chain of Nonlinear Coupled Oscillators Using Complex Variables. Nonlinear Dynamics 25(1), 95–109 (2001). DOI 10.1023/A:1012994430793

Matsuhisa, H., Gu, R., Wang, Y., Nishihara, O., Sato, S.: Vibration Control of a Ropeway Carrier by Passive Dynamic Vibration Absorbers. JSME international journal. Ser. C, Dynamics, control, robotics, design and manufacturing 38(4), 657–662 (1995). DOI 10.1299/jsmec1993.38.657

Vakakis, A.F., Gendelman, O.: Energy Pumping in Nonlinear Mechanical Oscillators: Part II. Resonance Capture. Journal of Applied Mechanics 68(1), 42 (2001). DOI 10.1115/1.1345525

Methodology for the robust design of a network of dynamic vibration absorbers

Kévin Jaboviste * [1], Emeline Sadoulet-Reboul [1], Nicolas Peyret [2], Charles Arnould [3], Eric Collard [3], Gaël Chevallier [1]

[1] Franche-Comté Électronique Mécanique, Thermique et Optique - Sciences et Technologies (UMR 6174) – Université de Franche-Comté, Centre National de la Recherche Scientifique : UMR6174, Ecole Nationale Supérieure de Mécanique et des Microtechniques, Université de Technologie de Belfort-Montbeliard – France

[2] Laboratoire QUARTZ-SUPMECA EA 7393 – Laboratoire QUARTZ EA 7393 - SUPMECA Paris, 3 rue Fernand Hainaut, 93400 Saint Ouen, France – France

[3] Thales LAS France – Thales (France) – France

The proposed work aims to provide a framework for the robust design of devices composed of a network of dynamic vibration absorbers known by the acronym MTMD (Multiple Tuned Mass Damper). The studied case is related to an aeronautic structure hosting a set of optronic devices sensitive to vibrations. This structure has a vibration mode that can be an issue in the frequency band of use that why the mitigation strategy is based on the implementation of an MTMD.
Firstly, a deterministic optimization based on the minimization of the elastic strain energy around the mode of interest is carried out in order to obtain an optimal frequency distribution of the MTMD. The influence of the number of absorbers composing the MTMD as well as the structural damping of the absorbers and their mass on the performance of the optimal solution is presented.

Moreover, this type of device is known to be sensitive to frequency tuning and it turns out that the eigenfrequency of the vibration mode of interest can be considered as a lack of knowledge during the operating cycle of the aeronautic structure. In this context, an epistemic uncertainty is introduced to represent this lack of knowledge. A robustness analysis based on the Info-Gap method, developed by Yakov Ben-Haim since the 1990s, is then implemented to quantify the performance of MTMD according to this source of uncertainty. The performance metric is constructed as the ratio between the elastic strain energy in the structure without MTMD and that with MTMD on the frequency band of interest. The influence of certain parameters on the robustness of the optimal solution is also studied.
Finally, a robust optimization procedure based on deterministic optimization and Info-Gap robustness analysis is proposed in order to make the optimal adjustment of the MTMD insensitive to the lack of knowledge considered over a certain range of variation. This methodology makes it possible to propose a distribution law of the absorbers of an MTMD guaranteeing the robustness of the network for a given horizon of uncertainties.

*Speaker

Smart Structures

Hybrid crankshaft control for the reduction of torsional vibrations and rotational irregularities

Guillaume Paillot * [1], Simon Chesne , Didier Remond

[1] Institut National des Sciences Appliquées de Lyon – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France. – France

In an internal combustion engine, the impulse initiated by the combustion of gas within the cylinders is able to put the crankshaft into a rotating movement, thus transmitting a torque to the wheels through the drivetrain. However, the movement of the piston is not uniform, and the transmitted torque is far from being constant at a steady engine regime. Indeed, the important pressure variations on the piston as well as the influence of the alternating masses inertia create a periodic oscillation around an average value in torque. This creates a similar oscillation in angular acceleration, speed, and position, which is commonly referred to as torsional irregularity or rotational irregularity.
This oscillation tends to generate unacceptable noises, such as rattling noise in the gearbox, and fatigues the drivetrain parts, shortening the operating lifetime. For these reasons, such irregularities need to be reduced, which is traditionally done by a flywheel located between the crankshaft and the gearbox. However, due to the downsizing of engines for fuel-consumption reasons, the simple flywheel is not enough anymore for acceptable noise levels.

This rotational irregularity phenomenon can be further amplified when the critical frequency of the crankshaft is a multiple of the current engine average speed. Here again, the downsizing is a problem as a crankshaft length reduction increases the critical frequency, enabling a larger spectrum of engine speeds to excite the resonance.

We develop here a new concept of a damper, based on the generation of a counteracting torque by a set of permanent magnets and coils, as in active ways of reducing torsional irregularities, coupled with the principle of the Tuned Mass Damper (TMD), efficient against resonance issues. The TMD is embedding a permanent magnet that moves in a coil. The variation of magnetic field produces an induced current that will feed the main coils.

The proposed model focuses on the determination of an efficient spatial layout of magnets to generate a corrective torque with the least possible energy consumption, with and without simplifying assumptions for inertia equations, and involving angular and time approaches for cyclic excitations and frequency resonances in order to tackle non-stationary operating conditions.

Keywords: Electromagnetic conversion; Rotating systems; Tuned Mass Dampers

*Speaker

References:

- *Acyclisme et vibrations*, JL. Ligier & E. Baron, Editions Technip, 2002

- *Energieeffiziente aktive Dämpfung von Torsionsschwingungen im KFZ-Antriebstrang*, J. Pfleghaar, TU München, 2014

- *Design development of Rotational Energy Harvesting Vibration Absorber*, F. Infante & Al., SMASIS 2018

- Patent *EP 2 910 813 A2*, MAN Truck & Bus AG, 2014
- Passive, Adaptive and Active Tuned Vibration Dampers – A Survey, J.Q. Sun, JVA Vol.117, pp 234-242, 1995

SEMI-ACTIVE TORSIONAL VIBRATIONS CONTROL OF A ROTOR USING A SMART ELECTRO-RHEOLOGICAL DYNAMIC ABSORBER

Yulan Sun * [1], Marc Thomas [2]

[1] École de Technologie Supérieure-Montréal – Canada
[2] École de technologie Superieure (ETS) – 1100 Notre Dame West, Montréal, H3C1K3, Québec,, Canada

Torsional rotor vibration is always very difficult to control since the implementation of a control system is not an easy task while the machine is rotating. Excessive torsional vibration can lead to failures of many mechanical components. A common method to control vibrations involves the use of dynamic absorbers. Due to their variable properties, smart materials may be used to increase the frequency range in order to control vibration. This article is concerned with the application of Electrorheological Fluids (ERF) to the reduction of torsional vibrations of a rotor by controlling damping and stiffness of a rotational dynamic absorber. A cylindrical type of electrorheological (ER) torsional absorber is designed and manufactured according to the required damping force level and the critical velocity of the rotor system. This paper presents torsional vibration control performance of a smart ER dynamic absorber using a bang-bang (ON-OFF) control strategy. The experimental results very closely approximate the simulation results. These results show that the ER dynamic absorber exhibits very good performances in terms of reducing the torsional vibration of rotor system.

Key words: Electrorheological fluids, torsional vibrations, dynamic absorber, Bang-Bang control, smart material.

References

- Troy; Hill, Charles L. (2009). Prevention Of Torsional Vibration Problems In Reciprocating Machinery.. Texas A&M University. Turbomachinery Laboratories. Winslow W.M., 1949. Induced vibration of suspensions. *Journal of applied physics.* **20**(12): 1137-1140.

*Speaker

Block H. and Kelly J.P., 1988. Review Article Electro-rheology. *Journal of Physics D: Applied Physics.* **21**: 1661-1667.

- Stanway R., Sprostonz J.L., and El-Wahedz A.K., 1996. Applications of electro-rheological fluids in vibration control: a survey. Smart Materals and Structures. 5: 464-482.

- Sun Y., Thomas M. and Masounave J., (2010). A quasi-Bingham model for predicting electrorheological fluid behaviour, Multidiscipline Modeling in Materials and Structures. 6 (1), 141-165.

Shunted piezoelectrical flextensionnal suspension for vibration insulation

Kevin Billon * [1], Nathan Montcoudiol [2], Alice Aubry [3], Rémi Pascual [3], Frederic Mosca [3], Frederic Jean [3], Charles Pézerat [4], Charlie Bricault [4], Simon Chesne [2]

[1] LaMCoS – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621 – France
[2] LaMCoS – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France. – France
[3] PYTHEAS Technology – PYTHEAS Technology, 100 Impasse des Houllières, ZA Le Pontet, F-13590 – France
[4] Laboratoire dácoustique de lúniversité du Mans – Le Mans Université, Centre National de la Recherche Scientifique : UMR6613 – France

The objective of the PyDAMP project is to develop a hybrid mechanical suspension to reduce the vibrations transmission on a wide frequency band. The undesired vibrations are generated by small electric motors (few kilograms). The concept of suspension is inspired by a Class IV flextensionnel transducer [1-3]. Flextensional transducers are a class of mechanical amplifiers composed of an active part, usually piezoelectric (bars, discs, rings), or magnetostrictive, and a shell that radiates in the surrounding fluid [4–6]. The suspension with piezoelectric pillar is developped by PYTHEAS Technology. A finite element study has been achieved to ensure the validity of the concept in terms of maximum admissible Von Mises stress, maximum displacement and modes shapes. An electromechanical model of the piezoelectrical suspension has been developed. Mechanical elements are converted in electrical components and an equivalent electrical circuit can be found. The electromechanical coupling of the transducer allows the introduction of mechanical damping and electric damping with different shunts based on resistor and negative capacitance [7, 8]. The simulation and the shunt optimisation are facilitated with only one physic, taking into account the whole dynamic behaviour of the piezoeletrical suspension.The piezoelectrical suspension is compared to a conventional viscoelastic suspension in terms of performances in the audible frequency range and validated using experimental tests.
1 : J. Butler and C. Sherman, Transducers and arrays for underwater sound, Springer, 2016.

2 : D. Jones and N. Abboud, "Performance analysis of a low-frequency barrel-stave flextensional projector," in Proceeding of ONR Transducer Materials and Transducers Workshop, pp. 1–4, 1996.

3 : N. Hagood, J. Aldrich, and A. V. Flotow, Design of passive piezoelectric damping for space structures, National Aeronautics and Space Administration, Langley Research Center, 1994.

4 : B. Damiri, Mod'ele analytique pour l'analyse du transducteur flextensionnel de classe IV dans l'air. PhD thesis, Lille 1, 1996.

*Speaker

5 : G. Brigham and L. Royster, ”Present status in the design of flextensional underwater acoustic transducers,” The Journal of the Acoustical Society of America **46**(1A), pp. 92–92, 1969.

6 : L. Royster, ”Predicting the effective dynamic coupling coefficient of the flextensional transducer (preliminary design considerations),” The Journal of the Acoustical Society of America **38**(5), pp. 879–880, 1965.

7 : A. Larky, ”Negative-impedance converters,” IRE Transactions on Circuit Theory **4**(3), pp. 124–131, 1957.

8 : B. De Marneffe and A. Preumont, ”Vibration damping with negative capacitance shunts : theory and experiment,”Smart Materials and Structures **17**(3), p. 035015, 2008.

Programmable band-gaps in periodic structures

Gaël Matten * [1], Morvan Ouisse [2], Gaël Chevallier [3], Manuel Collet [4], Kaijun Yi

[1] Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, CNRS/UFC/ENSMM/UTBM – Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, CNRS – France
[2] UBFC/FEMTO-ST – Univ. Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST CNRS, Univ.Bourgogne Franche-Comté, Institut FEMTO-ST, CNRS – Département Mécanique Appliquée 24 chemin de l'Epitaphe 25000 Besançon, France
[3] FEMTO-ST – UMR 6174 – femto – Université de Franche Comté 24, chemin de l'Épitaphe 25000 BESANÇON, France
[4] Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) – Ecole Centrale de Lyon – 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France

Using the periodicity of a mechanical structure to control its vibratory behavior is known for years. The periodicity creates a frequency range in which the energy cannot propagate. The periodicity is usually obtained through spatial repetition of a given shape and the corresponding band gaps are directly related to this shape and to the mechanical properties of the base cell. In this talk, a periodic structure with tunable band gaps is presented: shunted piezoelectric patches are embedded in the unit cells. A specific digital shunt circuit has been developed: it is used to program the local behavior law and updatable in real time. The obtained experimental results outperform the classical performance of passive material in terms of inertion loss and isolation.

*Speaker

Exploring periodicity and dispersion diagrams in muffler design

Vinicius D. Lima * [1], Belisario N. Huallpa *

[2], José Roberto Arruda *

[3]

[1] University of Campinas [Campinas] – Brazil
[2] Federal University of Lavras – Brazil
[3] Departamento de Mecânica Computacional, Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas (UNICAMP) – R. Mendeleyev, 200, 13083-860, Campinas-SP, Brazil

Periodic waveguides may be analyzed using dispersion diagrams, which plot the wavenumbers as functions of frequency. Imaginary wavenumbers mean propagation is not possible and, therefore, normal modes cannot build up. Muffler design has traditionally explored periodicity, but usually not using dispersion analysis. In this work, we show how to model one-dimensional acoustic waveguides with plane wave assumption using spectral elements (SE), how to obtain dispersion diagrams and, using semi-infinite elements, transmission loss from an SE model. The technological challenge consists in opening band gaps at low frequencies with a limited size muffler, and SE models are handy for low cost parameter optimization. For arbitrary shapes, this work uses scaled SE models or, alternatively, a state-space formulation recently developed by the authors. Additive manufacturing is an enabling technology for the implementation of the designed mufflers. In this work, we show experimental results for simple periodic mufflers built using 3D printing. The proposed simulation methodology is simple and can be used for quick design of 3D-printed polymer mufflers.

*Speaker

A new two-dimensionnal metastructure with acoustic frequency band gaps

Félix Demore * , Angela Madeo [1], Manuel Collet [2]

[1] GEOMAS, INSA Lyon – Institut National des Sciences Appliquées (INSA) - Lyon – 20 avenue Albert Einstein, 69621, Villeurbanne cedex, France, France
[2] Laboratoire de Tribologie et Dynamique des Systèmes (LTDS) – Ecole Centrale de Lyon – 36 Avenue Guy de Collongue, 69134 Ecully Cedex, France

A metamaterial inhibiting wave propagation at relatively low (acoustic) frequency range called "frequency
band gap" is proposed. Dispersion diagrams were obtained using the Bloch-Floquet method analysis – which
is presented here – with some FEM calculations are given. Numerical simulations are also introduced in order
to check the evanescence of elastic waves at the frequency range considered, allowing further experimental
validation of the considered cell.

*Speaker

Wednesday

Angular approaches

Angle domain inverse acoustic imaging for ICE powertrain combustion and mechanical noise identification

Claudio Colangeli * [1], Stefano Montani [1], Jeroen Lanslots [1], Sebastien Paillasseur [2], Fabio Bianciardi [1], Karl Janssens [1]

[1] Siemens Industry Software NV – Belgium
[2] MicrodB – Microdb – France

Acoustic imaging is adopted in automotive for the identification of the noise attributes of many sub-systems of the designed vehicle, including the engine and powertrain. In this paper we report on a procedure for the identification of the noise sources generated by an Internal Combustion Engine (ICE) as a function of the position of the crank shaft and its pistons. The studied approach relies on microphone array measurements and reference sensors data processed with a toolchain that allows to localize and quantify, within the combustion cycle, the major noise sources emitted by the ICE. The application of a cyclic Wiener filter, relying on reference cylinder pressure sensors, effectively decomposes the microphone array data into a combustion component, related to the thermal activity occurring inside the ICE, and a mechanical component, originating mainly from auxiliary systems in the powertrain. This requires a pre-processing in the angle domain, first, after which sound source localization is applied on angular ranges. The use of an inverse acoustic imaging algorithm, grounded on a Bayesian formulation, allows optimal spatial resolution also in the low frequency range, where the combustion noise contributors are prominent. The approach is demonstrated on engine test bench experimental data.

*Speaker

Angular vibration on-site measurements and application to torsional analysis on industrial cases

Francois Combet * [1], Louis Boisseleau [1]

[1] DYNAE – DYNAE, rue Condorcet, 38090 Villefontaine, France – France

The measurement and analysis of torsional phenomena remains an uncommon and challenging task to perform in the industry. The measurement of the torque via strain gauges provides explicit results but can be difficult to implement on-site and is generally limited to a low rotation speed. The motor current measurement is easier to perform but does not always reflect the torque instantaneous variations. The measurement of the Instantaneous Angular Speed (IAS) presents an interesting alternative as several techniques exist which are relatively easy to install on-site. This is classically performed using optical encoders or magnetic pickup sensors. A lesser known technique is based on Laser Torsional Vibrometry (LTV), using parallel beam laser vibrometers, which has the advantage of being totally non-intrusive. One difficulty however of IAS based diagnosis techniques is then to interpret the IAS amplitude, due to the lack of rules and criteria in this domain, on contrary to translational vibration. Advantages of these different techniques for IAS on-site measurements are discussed, and applications are then presented on industrial cases: the test and certification of the coupling of a fuel injection pump and the torsional analysis of the flexible coupling of a Diesel-generator group.

*Speaker

Towards the use of hybrid models for diagnosis and prognosis in turbomachinery health management

Stephan Heyns * [1], Brian Ellis , David Diamond , Ronald Du Toit

[1] University of Pretoria [South Africa] – South Africa

Failures of turbomachinery are often caused by the dynamic behaviour of rotating blades in these machines. The financial and production implications of such failures may be very significant and appropriate blade condition monitoring methodologies are therefore of critical importance [2]. Blade tip timing (BTT) is a non-intrusive measurement technique for online measurement of turbomachine vibration. Essentially it senses when a blade passes a number of proximity probes distributed circumferentially and mounted radially through the turbomachine casing above the row of rotor blades being measured, to determine the time of arrival. This can be linked to the blade vibration by employing an accurate measure of the once per revolution reference signal. The technique is non-intrusive and online monitoring is possible.
BTT is therefore often regarded as a feasible technique to track the condition of turbomachine blades, thus preventing unexpected and catastrophic failures. The processing of BTT data to find the associated vibration characteristics is however non-trivial. In addition, these vibration characteristics are difficult to validate, therefore resulting in great uncertainty of the reliability of BTT techniques. To deal with the uncertainties of the method, various new concepts have been introduced [2,3]. These ideas deal primarily with diagnosis. Techniques for prognosis to assist with maintenance decision making is however becoming more important. Mishra et al. [4] explored a range of techniques of interest to accomplish this through the use of hybrid models that merge physics based and a data driven approaches into a unified approach.

This idea is pursued further in the context of turbomachinery blades, by proposing an approach comprising a stochastic Finite Element Model (FEM) based modal analysis and a Bayesian Linear Regression (BLR) based BTT technique. The use of this stochastic hybrid approach is demonstrated for the identification and classification of turbomachine blade damage. For the purposes of this demonstration, discrete damage is incrementally introduced to a simplified test blade of an experimental rotor setup. The damage identification and classification processes are further used to determine whether a damage threshold has been reached, therefore providing sufficient evidence to schedule a turbomachine outage. It is shown that the proposed stochastic hybrid approach may offer many short- and long-term benefits for practical implementation.
In the present work, some limitations of existing work [5] are critically discussed and further refinement of the methodology is explored.

*Speaker

Condition Monitoring

CMBase, a universal gateway to condition monitoring datasets

Cécile Capdessus * [1], Frédéric Bonnardot *

2

[1] Laboratoire Pluridisciplinaire de Recherche en Ingénierie et Systèmes, Mécanique, Energétique (PRISME) – Université d'Orléans – 21 Rue Loigny-la-Bataille 28000 Chartres, France
[2] Laboratoire dÁnalyse des Signaux et des Processus Industriels – Université Jean Monnet [Saint-Etienne] : EA3059 – France

Condition monitoring is a lively research domain, with hundreds of researchers sharing new techniques coping with complex problems, such as variability of the operating conditions, complex machinery monitoring, diagnostics, prognosis... Considering the many methods that have been proposed these last decades, it is striking how few of them have reached the industrial application. One of the reasons is that the intensive validation of these methods over real-life data required to ensure their reliability is often difficult to achieve. The results obtained over one dataset may not be easily reproduced over another one. Furthermore, can the comparison between two techniques be objective, when applied to different datasets?
Some laboratories and companies generously share the datasets recorded on their test benches or industrial devices. Unhappily, it is often difficult for them to know for certain who has worked on their data, which is both frustrating and a real problem when they report to their authority about the diffusion of the data, in order to get the subsidies required for the test bench exploitation. From the user's point of view, there can also be difficulties in finding the right datasets for a specific study among the jungle of all that is proposed on the web. How to find the appropriate dataset for a prognosis study, or a fatigue study, or the study of any specific kind of damage? Another problem can be met by those who wish to share their datasets with the scientific community but do not have the technical skills or staff to do so.
CM Base is a web portal that aims at facilitating the sharing of the data, by offering many a functionality, such as a list of all the existing datasets and test benches with all related papers, searching facility allowing to extract from the base all datasets related to a specific problem or papers related to a specific dataset.

*Speaker

Experimental investigation of sensor mounting positions for localized faults detection of epicyclic gear sets

Yu Guo * [1], Liu Zhen [1], Xing Wu [1], Yinxin Yu [1]

[1] Kunming University of Science and Technology – China

In the literature reports on the vibration based localized faults detection of epicyclic gear sets, the vibration sensor is often mounted on the ring gear or the housing adjacent to the ring gear, which ensures the vibration transfer path between the mesh point of the ring-plant gear pairs and the sensor is the shortest when the planet gear is under passing the sensor and the corresponding vibration has the highest signal-noise ratio (SNR). However, this sensor mounting position is often too ideal to be utilized in applications. For example, three types of structures of epicyclical gear sets commonly used are shown in Fig.1. It is noted that the ring gears can be rotated in Fig. 1 (b) and (c), which are challenge for selecting a suitable sensor mounting position. As well-known that the bearing housing utilized as the sensor mounting position for a fixed-axis gearbox is widely adopted in applications. However, the bearing housing sensor mounting for the vibration analysis of epicyclic gear sets is still an issue. It has two drawbacks for the vibration picking. Firstly, the vibration transfer path is much longer than that of the sensor mounted on the ring gear. Secondly, the noise from adjacent bearings can lead into the picked vibration. Then, the bearing housing sensor mounting is few reported in the literature. On the other hand, the bearing housing sensor mounting can be implemented in most applications of epicyclic gear sets. Then, it is worth investigating whether the bearing housing sensor mounting can be employed for the localized faults detection of epicyclic gear sets. To address this issue, an experimental investigation has been carried out on a planetary gearbox test rig for the vibration based tooth-root crack faults detection. Experimental results show that the fault feature contained in the observed vibration from bearing housing is weaker than that obtained from ring gear position. However, the bearing housing sensor mounting can also be utilized for the vibration based tooth faults detection by using the well-known vibration separation and the synchronous average techniques. The spectra of the vibrations picked up at the two mounting positions are shown in Fig.2, where the characteristic order (3.55X) and its harmonics related to the tooth-root crack of a planet gear order are exposed clearly.

*Speaker

Towards 3D AFM Using Multiple Vibration Modes

Eyal Rubin * [1], Izhak Bucher [1], Solomon Davis [1]

[1] Dynamics Laboratory, Mechanical Engineering, Technion – Israel

Atomic force microscopy (AFM) is used for measuring nano-scale topographic features. By exciting a micro-cantilever with a sharp stylus at its tip, at or near resonance, a Frequency Modulated AFM (FM-AFM) device can sense the change of resonance frequency due to the change in tip-surface Van der Waals (VdW) potential. The topography is then retrieved from the relationship between the potential and the distance between stylus and the specimen. To improve the measurement speed and address complex geometries emerging in industrial microchip constructions, several enhancements are introduced. While most FM-AFM devices operate in a single vibrating mode, this article enhances existing sensing methods by extending to multi-dimensional sensing the resonance frequencies that are modulated by the topology, in several orthogonal vibration modes simultaneously. The latter opens new possibilities, e.g. to measure steep walls and trenches or other complex geometries. An Autoresonance (AR) control scheme for faster excitation, and fast frequency estimation algorithm were used for sensing several modes simultaneously, without the need to wait for steady state settling of the cantilever. The concept was tested on a large-scale experimental system, where VdW forces between tip to surface were replaced by magnetic forces, using a magnetic tip and ferromagnetic samples. Experimental results employ 3D relevant topographies such as inclined surfaces, steep walls and trenches that were reconstructed experimentally with 4 (μm) resolution or better. Downscaling to typical AFM dimensions would theoretically yield sub-nanometer resolution. Numerical and experimental data are shown to demonstrate the advantageous of the new approach.

*Speaker

Fault diagnosis and prognosis for rolling bearings

Early bearing defect detection in a noisy environment based on a method combining singular value decomposition and empirical mode decomposition

Mourad Kedadouche [2,1], Zhaoheng Liu [1,2], Marc Thomas * [1,3]

[2] Ecole de Technologie Supérieure (ETS) – 1100, rue Notre-Dame Ouest Montréal (Qc) H3C 1K3 Canada, Canada
[1] Ecole de Technologie Supérieure [Montréal] – Canada
[3] École de technologie Superieure (ETS) – 1100 Notre Dame West, Montréal, H3C1K3, Québec,, Canada

Abstract This paper thus proposes a new method combining Empirical Mode Decomposition (EMD) and Singular Value Decomposition (SVD) for bearing fault diagnosis. The method includes three steps. First, the signal is decomposed using EMD. Second, the instantaneous amplitudes are computed for each component using the Hilbert Transform (HT). Lastly, the Singular Value Vector is applied to the matrix of Cross-Power Spectral Density (CPSD) of the instantaneous amplitude matrix and the SVD versus frequency is analysed. The proposed method is first validated by using various noisy simulated signals. The results show that the proposed method is robust versus the noise to detect the bearing frequencies that are representative of the defect even in a very noisy environment and that the amplitude of the first SVD at each bearing frequency is very sensitive to the defect severity. The proposed method is also applied to two different experimental cases with very low degradation. The results show that the proposed method is able to detect bearing defects at an early stage of degradation for both experimental cases.

Keywords: Bearing fault, Empirical Mode Decomposition (EMD), Hilbert transform (HT), Cross-Power Spectral Density (CPSD), Singular Value Decomposition (SVD).

References

Lei, Y. G., Lin, J., He, Z. J. and Zuo, M. J. "A review on empirical mode decomposition in fault diagnosis of rotating machinery". *Mechanical Systems and Signal Processing,* vol. 35, no. 1-2, (2012): 108-126.

Cong, F., Chen, J., Dong, G. and Zhao, F. "Short-time matrix series based singular value decomposition for rolling bearing fault diagnosis". *Mechanical Systems and Signal Processing*, vol. 34, no. 1 (2013): 218-230.

*Speaker

Prognostics of rolling element bearings based on Entropy indicators and Particle Filtering

Junyu Qi * [1,2], Alexandre Mauricio [1,2], Gryllias Konstantinos [1,2]

[1] Division PMA, Department of Mechanical Engineering, Faculty of Engineering Science, KU Leuven – Belgium
[2] Dynamics of Mechanical and Mechatronic Systems, Flanders Make – Belgium

Rolling element bearings' damage is the main cause for unexpected breakdown in rotating machinery. Therefore there is a continuous industrial interest on condition monitoring of bearings targeting towards the development and proposal of robust diagnostic techniques which can detect accurately, robustly and early the generation of the fault. On the other hand, industry is not interested only in the proper damage detection and identification of faults but is mainly targeting towards the robust estimation of the Remaining Useful Life (RUL) of machine elements. The proper estimation of the RUL could be linked directly with the maintenance planning and warehouse organization providing immediately profits in terms of employees health and safety, environmental protection and continuous production. A plethora of diagnostics and prognostics indicators have been proposed during the last decade focusing towards the accurate representation and tracking of the health state of bearings and other machine elements. However, in certain cases (e.g. nonstationary operating conditions), the classic techniques for bearings prognostics (e.g. statistical analysis, frequency analysis and time-frequency analysis) underperform due to the high noise influence or the high machines' complexity. Therefore the classical diagnostics indicators may identify the fault quite late and fail to identify properly the RUL.
In this paper, prognostics indicators based on the measurement of disorder (e.g. entropy) are used in order to track the degradation severity of the machinery. The Spectral Entropy (SE) [1], the Envelope Spectral Entropy (ESE) and the Spectral Negentropy(SN) [2] are used as prognostics indicators in parallel with the Spectra Kurtosis [3] and the RMS. The indicators are estimated on the well-known bearing dataset Prognostia and Particle filtering is used in order to estimate the Remaining Useful Life of bearings. The prognostics indicators are evaluated and compared based on four main criteria: the Monotonicity, the Trendability and the Prognosability as well as on the estimated RUL.

Keywords: Condition Monitoring, Feature extraction, Spectral Entropy, Prognostics, Remaining Useful Life

References:

Pan, Y. N., J. Chen, and X. L. Li. "Spectral Entropy: A Complementary Index for Rolling Element Bearing Performance Degradation Assessment." Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science. Vol. 223, Issue 5, 2009,

*Speaker

pp. 1223–1231.

Antoni, J. " The infogram: Entropic evidence of the signature of repetitive transients." Mechanical Systems and Signal Processing. Vol. 74, 1 June 2016, pp. 73–94.

Antoni, J. " The spectral kurtosis: a useful tool for characterizing non-stationary signals." Mechanical Systems and Signal Processing. Vol. 20, Issue 2, February 2006, pp. 282–307.

Spall Evolution in a Rolling Element Bearing

Dmitri Gazizulin * , Renata Klein [1], Jacob Bortman [2]

[1] R.K. Diagnostics – Gilon, P.O.B. 101, D.N. Misgav 20103, Israel
[2] PHM Lab, Department of Mechanical Engineering, Ben-Gurion University of the Negev, – P.O. Box 653, Beer Sheva 84105, Israel

Failure prognosis of rolling element bearings (REBs) is crucial in rotating machinery PHM. The damage evolution in REBs consists of two main phases: damage initiation and propagation. The conventional REB life models address the lifetime of the bearing to the damage initiation, i.e. first defect formation [1]. However, after the first defect formation, the bearing might be fully operational for millions of cycles. After the first defect formation, it propagates in the circumferential direction of the raceway, until the bearing becomes non-operational [2]. Many diagnostic tools have been developed in order to monitor the defect propagation, in contrast to prognostic tools which are still lacking. In order to build an efficient and accurate prognostic tool, the damage mechanism during the propagation phase must be understood. For this purpose, a physics-based model of a spalled bearing has been developed. The model aims to study the material behavior at the trailing edge of the spall during the rolling element (RE) impact. It integrates a non-linear dynamic [3] and finite element (FE) models. The dynamic model adds insights regarding the dynamic response of a faulty bearing. However, this model cannot provide information regarding the damage accumulation as a result of RE-spall edge interaction. Thus, the results of the dynamic model are used as an input to the FE model. A qualitative damage analysis for crack evolution within the spall edge was conducted. Moreover, a metallurgical analysis of the bearing from endurance tests was carried out. The metallurgical analysis added insights regarding the damage mechanism and was used for model validation. The results achieved from the damage analysis are in good agreement with the experimental observations. To our best knowledge, this is the first study attempting to simulate damage evolution within the spall edge based on physical insight.
Keywords:

Rolling elements bearing, non-linear dynamic modeling, finite element modeling, spall propagation

Reference

Sadeghi, F., Jalalahmadi, B., Slack, T.S., Raje, N. and Arakere, N.K., 2009. A review of rolling contact fatigue. Journal of tribology, 131(4), p.041403.

Rosado, L., Forster, N.H., Thompson, K.L. and Cooke, J.W., 2009. Rolling contact fatigue life and spall propagation of AISI M50, M50NiL, and AISI 52100, Part I: experimental results.

*Speaker

Tribology Transactions, 53(1), pp.29-41.
Kogan, G., Bortman, J. and Klein, R., 2017. A new model for spall-rolling-element interaction. *Nonlinear Dynamics*, *87*(1), pp.219-236.

Data Mining Classification & Machine Learning methods

Multi-label fault diagnosis based on Convolutional Neural Network and Cyclic Spectral Coherence

Zhuyun Chen [1], Alexandre Mauricio [2,3], Weihua Li [1], Konstantinos Gryllias * [2,3]

[1] School of Mechanical and Automotive Engineering – South China University of Technology, Guangzhou 510640, China
[2] Dynamics of Mechanical and Mechatronic Systems, Flanders Make – Belgium
[3] KU Leuven, Faculty of Engineering Science, Department of Mechanical Engineering, Division PMA, Celestijnenlaan 300 B, B-3001, Heverlee – Belgium

Rotating machines are widely used in manufacturing industry, where sudden failures of key components such as bearings may lead to unexpected breakdown of machines and cause economic loss and human casualties. In addition, machines usually are operating under variable working conditions leading to the dynamic changes of fault characteristic, thus presenting big challenges of reliable and accurate fault diagnosis. Data-driven based deep learning fault diagnosis methods are powerful tools to capture hierarchical features from raw input to classify fault patterns by stacking multiple non-linear transformation layers. Deep models are constructed and trained, relying on huge historical data and requiring less expert knowledge to obtain decision-making. These techniques present high effectiveness and advantages in many intelligent fault diagnosis tasks. However, deep learning algorithms require a large amount of training data to fit on multiple non-linear functions, which often makes the trained network, in general, prone to over-fitting on small datasets. The models tend to perform well on the training data, but not so well on the testing data. Moreover, those methods utilize single point-estimates as weights to implement classification, in which, the distributions of weight parameters through the neural network layers are unknown. Thus they usually provide normalized score vectors and are unable to reveal the model uncertainty [1], which is important for accurate and reliable diagnosis and decision making in the field of condition monitoring. In this paper, a cyclostationary-based tool is combined with a Bayesian Convolutional Neural Network in order to tackle these problems. Firstly, the Cyclic Spectral Correlation (CSC) is adopted to capture correlation features of periodic phenomenon in the frequency domain. CSC is a bi-variable map of two frequency values, which is sensitive to the level of cyclostationary [2-3]. This 2D matrix can be used to enhance/reveal the cyclostationary nature of the signature masked by strong noise, characterizing the fault vibration signals obtained from rotating machinery operating under varying conditions. Moreover the Bayesian Convolutional Neural Network, which is a variant of Convolutional Neural Network, is proposed in order to process the uncertainty and to predict the output distribution for each class. The Bayesian Convolutional Neural Network integrates the prior probability distribution to the weights of all convolutional and fully-connected layers, obtaining the epistemic uncertainty, by capturing the weights variation for given input data

*Speaker

and the aleatoric uncertainty estimated over the output of the model [4]. The model can be effectively updated to learn feature representations and obtain predictions according to Bayes' theorem with variational inference. The proposed method is tested and evaluated on an experimental study of rolling element bearing fault diagnosis, where datasets have been collected under variable working conditions. The results demonstrate that the proposed method achieves good classification performance and superiority compared with other state of the art approaches.
Keywords: Fault diagnosis; Cyclic Spectral Correlation; Bayesian Convolutional Neural Network; Rolling element bearings

References:

Kendall, A., & Gal, Y.. What uncertainties do we need in bayesian deep learning for computer vision?. In *Advances in neural information processing systems*, pp. 5574-5584 (2017

Antoni, J., Cyclic spectral analysis in practice, Mechanical Systems and Signal Processing, 21, 597 – 630 (2007).

Mauricio, A., Qi, J., Gryllias, K., Sarrazin, M., Janssens, K., Smith, W., & Randall, R. Cyclostationary-based bearing diagnostics under electromagnetic interference. In *25th International Congress on Sound and Vibration 2018, ICSV 2018: Hiroshima Calling*, Vol. 5, pp. 2860-2867 (2018)

Shridhar, K., Laumann, F., & Liwicki, M. A Comprehensive guide to Bayesian Convolutional Neural Network with Variational Inference. *arXiv preprint arXiv:1901.02731* (2019)

A semi-supervised Support Vector Data Description- based fault detection method for rolling element bearings based on Cyclic Spectral Coherence

Chenyu Liu * [1,2], Konstantinos Gryllias [1,2]

[1] Division PMA, Department of Mechanical Engineering, Faculty of Engineering Science, KU Leuven – Belgium

[2] Dynamics of Mechanical and Mechatronic Systems, Flanders Make – Belgium

Health condition of rolling element bearings has a significant impact on rotational machinery systems. The failure of bearings may cause a total breakdown of machinery and may even lead to a fatal accident. Therefore, the early bearing fault detection and identification arises as a critical mission in the frames of predictive maintenance, receiving the last years extensive attention. Nowadays advances signal processing techniques are combined with high level machine learning approaches focusing towards automatic fault diagnosis. On the other hand in real industrial conditions, the available data belong mainly in the healthy operating condition and the faulty datasets are rather limited. Therefore the standard machine learning approaches, which are based on the training of a number of classes cannot be realistically used. In order to overcome this limitation semi supervised/anomaly detection techniques have been proposed which are based on the training of the methodology exclusively on healthy data. Before the application of the anomaly detection methodology, a diagnostic indicator, which accurately tracked the degradation of the system, should be extracted. A plethora of diagnostic indicators have been proposed including time domain indicators (RMS, kurtosis, skewness etc.) as well as frequency domain indicator (amplitudes at specific fault characteristic frequencies: BPFI, BPFO, BSF etc.). Signal processing and spectral analysis methods such as the Squared Envelope Spectrum (SES) are also used to extract features which can detect bearing faults accurately[1]. The anomaly detection focuses on setting a threshold at the indicators in order to separate the anomalous samples from the normal ones. Support Vector Machine (SVM) is one of the most popular semi-supervised methods since it can effectively isolate anomalies by fitting a hyperplane and projecting features into a higher dimension [2]. On the other hand, the minimization of the false alarms and misdetections for bearing anomaly detection is still a challenging task.
In this paper the SVDD anomaly detection techniques is combined with advanced diagnostic indicators which are based on cyclostationarity. Cyclic Spectral Correlation (CSC) and Cyclic Spectral Coherence (CSCoh) have been proved as powerful tools in signal cyclostationary analysis [3]. They represent the potential fault modulation information into frequency-frequency domain bivariable maps. The integration over the cyclic frequency, leads to the estimation of the Enhanced Envelope Spectrum (EES), which demonstrates the modulation frequencies and their harmonics. Due to the periodic mechanism of the bearing faults' impacts, the EES can provide a clearer detection of bearing faults comparing to SES. Therefore, the sum of the amplitudes

*Speaker

of the harmonics of the bearing characteristic fault frequencies of EES are extracted as diagnostic indicators. Meanwhile, the semi-supervised Support Vector Data Description (SVDD) is used as a detector. Instead of a hyperplane, SVDD fits a hypersphere for fault isolation and can be extended in the nonlinear case with a kernel trick [4]. In this paper, the EES-based diagnostic indicators and the SVDD detector are combined and the methodology is tested and evaluated on experimental data for bearing fault detection. The results demonstrate the efficacy of the method presenting high detection rate with low false alarm and misdetection rate.

References

. Mauricio, A., Qi, J., & Gryllias, K. (2019). Vibration-Based Condition Monitoring of Wind Turbine Gearboxes Based on Cyclostationary Analysis. Journal of Engineering for Gas Turbines and Power, 141(3), 031026.

. Widodo, A., & Yang, B. S. (2007). Support vector machine in machine condition monitoring and fault diagnosis. Mechanical systems and signal processing, 21(6), 2560-2574.

. Antoni, J. (2007). Cyclic spectral analysis of rolling-element bearing signals: Facts and fictions. Journal of Sound and vibration, 304(3-5), 497-529.

. Tax, D. M., & Duin, R. P. (2004). Support vector data description. Machine learning, 54(1), 45-66.

Big vibration data identification of bearing fault base on autoencoder network-based feature representation and optimal LSSVM-PSO classifier model

V Hung Nguyen * [1,2]

[1] TienDung Hoang – Vietnam
[2] JunSheng Cheng – China

In this paper, based on deep learning method for the high-dimensional feature representation of vibration signal and optimal machine learning model, a new diagnosis technique for multi-level fault of roller bearing is proposed. Firstly, a deep learning network based on stacked autoencoders (SAE) with two hidden layers is exploited for vibration feature extraction (VFE) of roller bearing fault signal, named as VFE-SAE, in which the unsupervised learning algorithm is used to reveal the significant properties in the data such as nonlinear, non-station properties. The extracted features can provide good discriminability for fault diagnosis task. Secondly, an optimal classifier model based on least square support vector machine (LSSVM) classifier and particle swarm optimization (PSO), named as LSSVM-PSO, is used to perform supervised fine-turning and classification. In which, the classifier model is trained with the labeled features to identify the target data. Especially, in this work by the transfer learning the performance of bearing fault diagnosis technique can be tuned. That is, the features of target vibration signal can be extracted by the learning of feature representation which depends on the weight matrix of hidden layers of VFE-SAE method. The experimental results by analyzing the roller bearing vibration signals with multi-status of fault have demonstrated that the VFE-SAE based feature extraction in conjunction with the LSSVM-PSO classifier model can achieve higher accuracies than the other popular classifier models.

*Speaker

Machine teaching to optimize algorithms performances on restricted dataset.

Alexandre Carbonelli * [1], Maurin Waussen *

[2]

[1] VIBRATEC (VIBRATEC) – vibratec – 28 CHEMIN DU PETIT BOIS, 6930 ECULLY, France
[2] VIBRATEC – vibratec – France

Machine Learning techniques open important ways of development of physical models in almost every field. Performances reached rely on two major pillars: the (physical) model and the data. When a huge amount of data is available, the intrinsic characteristics of the chosen algorithm become less critical. On the other hand, with limited amount of data, all the human knowledge on the system to be modelled becomes critical to exploit. One of the multiple applications of Machine Learning (ML) technics concerns the meta-models. Indeed, in this paper, we show how we can bypass a computation scheme by using clever regression models. The approach is performed on a system from which we want to know instantaneously the first natural frequencies without performing each time finite elements (FE) computation. We study the performance reached by studying the number of training cases required to teach the algorithm how to link inputs to outputs within a satisfying accuracy. Different algorithms are tested with very encouraging results as going into higher dimensional problem. The final aim of this study is to provide global guidelines for the most efficient Machine Teaching.

*Speaker

Effects of the Particle Swarm Optimization parameters for structural dynamic monitoring of cantilever beam

Xiao-Lin Li * [1], Roger Serra [1], Julien Olivier [2]

[1] Laboratoire de Mécanique Gabriel Lamé – Institut National des Sciences Appliquées - Centre Val de Loire : EA7494 – France

[2] Laboratoire dÍnformatique Fondamentale et Appliquée de Tours – Institut National des Sciences Appliquées - Centre Val de Loire : EA6300, Institut National des Sciences Appliquées - Centre Val de Loire : EA6300 – France

Nowadays, particle swarm optimization (PSO) algorithm has become a widespread optimization method. However, it is well known that its main parameters (inertia weight, two learning factors, velocity constraint and population size) have a critical effect on its performance. Currently the effects of PSO parameters on structural health monitoring have not been comprehensively studied. Therefore, in this paper, the PSO algorithm is used for damage detection assessment of a cantilever beam, and the simulation results are used to analyze the effects of PSO parameters. There are five levels for each parameter in our experiment, mean fitness value and success rate for each level are used as criteria to measure the convergence and stability of the PSO algorithm. Considering the effect of population size on CPU time, a trade-off strategy is presented to further determine the selection of population size.

Keywords:

Particle Swarm Optimization, Parameter Selection, Structural Damage Detection, Cantilever Beam.

References:

J. Kennedy and R.C. Eberhart,Particle swarm optimization, Proceedings of IEEE international conference on neural networks, 1995.

M. Jiang, Y. P. Luo and S. Y. Uang, Particle Swarm Optimization - Stochastic Trajectory Analysis and Parameter Selection , Swarm Intelligence: Focus on Ant and Particle Swarm Optimization, 2007.

Y.T. Dai, L. Q Liu, Y. Li, An Intelligent Parameter Selection Method for Particle Swarm Optimization Algorithm, Computational Sciences and Optimization (CSO), 2011.

R. Serra, J. Olivier, Apport de l'optimisation par essaims particulaires pour la détection de modifications structurelles à partir des propriétés dynamiques, Congrés Français de Mécanique 2017.

*Speaker

The virtual machine : a signal generator based on realistic dynamic behavior

Didier Remond * [1], Adeline Bourdon *

1

[1] Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France – Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France, Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France. – France

Condition monitoring of rotating machines is largely based on signal processing techniques involving different approaches in time, cyclic or angular domains with various numerical tools. Generally speaking authors extract simple models from literature analysis in order to generate some test signals dedicated to the demonstration of effectiveness and efficiency of the proposed method. Most of the time, the signal of interest is a vibration signal and this analytic signal is constructed by a convolution of an impulse excitation through a transfer function and some added perturbations or noise. The transfer function generally describes a single DoF with a resonance frequency including damping coefficient. Impulse excitation is generated by some assumptions on a shock when fault enters in a contact zone in gears or bearings. This analytic signal simulation suffers from strong assumptions, strong drawbacks and lacks in order to describe more realistic dynamic behaviors in rotating machines. Some of them may be listed in the following:

- There is no direct link between geometry, in particular fault geometry, and excitation characteristics (impulse duration, amplitude, ...),
- These signals are related to a 1D model where excitation and sensor are placed in the same direction,
- There is no way to investigate other signals or physical quantities in order to understand the meaning of indicators extracted from signal analyses,
- It is very difficult to compare signal analyses on a reference basis,
- Cyclic and time descriptions are generally merged in a time description, assuming a constant rotation speed of the machine,
- Sensor transfer function or model describing sensor and signal acquisition are not included in the signal generation process.

The present paper presents a "simple" model which includes realistic structural parts, fixed or in rotation, linked together with mechanical components like bearings or gears (see Fig. 1).

*Speaker

These linking elements are described as restitution forces between structural parts with light but realistic models related to technological parameters. For sake of illustration, load sharing over roller elements in bearings will be held as instance of coupling between constant radial load applied on the shaft and torque variations on the rotating shaft. Various external excitations may also be added as resistive torque fluctuations or external forces located in realistic positions. As this model keeps the rotating DoF of at least one shaft, the angle-time function is known during simulation, allowing the description of cyclic and time phenomena in a precise and simultaneous way. Some symptomatic results will be presented showing for instance some modulation effects on vibration signals which are linked to mechanical couplings between shafts. Non stationary operating conditions in speed will be also illustrated as strong perspectives for realistic signal generation of different natures. The software will be available online as p-code and m files for Matlab ©.

List of participants

- Abboud Dany
- Abdenour Soualhi
- Addou Yacine
- Aghazadeh Fatemeh
- Alcorta Roberto
- Andre Hugo
- Antoni Jérôme
- Arruda Jose Roberto
- Assoumane Amadou
- Astolfi Davide
- Audebert Sylvie
- Bachar Lior
- Baguet Sébastien
- Bajric Rusmir
- Barcet Sylvain
- Bareille Olivier
- Baudin Sophie
- Benaicha Youness
- Berger Sébastien
- Bertoni Renaud
- Billon Kevin
- Blanchard Corentin
- Bonnardot Frédéric
- Borghesani Pietro
- Bortman Jacob

- Bouhaddi Noureddine
- Bruand Guillaume
- Camerini Valerio
- Carbonelli Alexandre
- Castellani Francesco
- Cédric Peeters
- Chiementin Xavier
- Cocconcelli Marco
- Combet Francois
- Daga Alessandro Paolo
- Dallali Manel
- Darraz Abdelhakim
- Demore Félix
- Dimitrijevic Zoran
- Dion Jean-Luc
- Dollon Quentin
- Dubey Anurag
- Ege Kerem
- El Badaoui Mohamed
- Eltabach Mario
- Gagnon Martin
- Gao Hanwei
- Garibaldi Luigi
- Garnell Emil
- Gazizulin Dmitri
- Griffaton Julien
- Gryllias Konstantinos
- Guo Yu
- Heyns Stephan
- Hurel Gabriel
- Jaboviste Kévin
- Kehr-Candille Veronique

- Kieu Thinh
- Koechlin Samuel
- Lacaze Florian
- Le Deunf Meryem
- Leaman Felix
- Lerouge Matthieu
- Li Xiaowen
- Li Xiao-Lin
- Liu Chenyu
- Liu Hongcheng
- Lizoul Khalid
- Maamar Asia
- Macchi Lucas
- Manin Lionel
- Marcel Lucie
- Martin Guillaume
- Matania Omri
- Matten Gaël
- Mauricio Alexandre
- Melot Adrien
- Molina Vicuna Cristián
- Naccarato Gianni
- Ompusunggu Agusmian
- Ouisse Morvan
- Paillot Guillaume
- Passos Sébastien
- Perez Matthias
- Pham Quang Hung
- Pichard Géraldine
- Proteau Antoine
- Qi Junyu
- Qin Yi

- Quoc-Cuong Nguyen
- Rubin Eyal
- Sadoulet-Reboul Emeline
- Sanches Leonardo
- Sauvage Olivier
- Schmidt Stephan
- Serra Roger
- Sghaier Emna
- Sierra-Alonso Edgar F.
- Snoun Cherif
- Soave Elia
- Sun Yulan
- Telbani Afaf
- Teloli Rafael
- Thomas Marc
- Thomas Jean-Hugh
- Thomas Xavier
- Topenot Margaux
- Troncossi Marco
- Vouagner Pascal
- Vyas Nalinaksh
- Wang Yuzhu
- Wang Yi
- Weisser Thomas
- Woussen Maurin
- Xiang Sheng
- Xiong Yiwei
- Yoann Hebrard
- Zhang Xin

Author Index