



KU Leuven  
Department of Mechanical Engineering  
LMSD (Mecha(tro)nic System Dynamics)  
Celestijnenlaan 300 - box 2420  
B-3001 Heverlee, Belgium

Proceedings of

**ISMA2024**

International Conference on  
**Noise and Vibration Engineering**

**USD2024**

International Conference on  
**Uncertainty in Structural Dynamics**



9 to 11 September, 2024

Editors: W. Desmet, B. Pluymers, D. Moens, J. del Fresno Zarza.

© KU Leuven, Departement Werktuigkunde, LMSD (Mecha(tro)nic System Dynamics)  
Celestijnenlaan 300 - box 2420, B-3001 Heverlee, Belgium

Alle rechten voorbehouden. Niets uit deze uitgave mag worden vemenigvuldigd en/of openbaar gemaakt worden door middel van druk, fotokopie, microfilm, elektronisch of op welke andere wijze ook zonder voorafgaandelijke schriftelijke toestemming van de uitgever.

All rights reserved. No part of the publication may be reproduced in any form by print, photoprint, microfilm or any other means without written permission from the publisher.

ISBN 978-90-82893-17-5

Proceedings of

**ISMA2024**

International Conference on  
**Noise and Vibration Engineering**

**USD2024**

International Conference on  
**Uncertainty in Structural Dynamics**

Leuven  
9 to 11 September, 2024

## **Organising Committee:**

W. Desmet	<i>ISMA Conference Chairman</i>
B. Pluymers	<i>ISMA Conference Chairman</i>
P. Sas	<i>ISMA Honorary Chairman</i>
D. Moens	<i>USD Conference Chairman</i>
D. Vandepitte	<i>Programme Chairman</i>
D. Chronopoulos	<i>Conference Programme</i>
C. Claeys	<i>Conference Programme</i>
W. De Roeck	<i>Conference Programme</i>
E. Deckers	<i>Conference Programme</i>
H. Denayer	<i>Conference Programme</i>
K. Gryllias	<i>Conference Programme</i>
P. Kundu	<i>Conference Programme</i>
F. Naets	<i>Conference Programme</i>
G. Serhat	<i>Conference Programme</i>
H. Van der Auweraer	<i>Conference Programme</i>
D. Bortels	<i>Conference Manager</i>
T. Willems, B. Geutjens	<i>Technical Manager</i>
T. Engelbosch	<i>Conference Secretary</i>
J. del Fresno Zarza	<i>Conference Proceedings and Webmaster</i>
J. Staiger	<i>Exhibition</i>
A. M. Zadeh Fard	<i>Public Relations</i>
V. Cool	<i>Social Events</i>

## **Organised by:**

KU Leuven, Department of Mechanical Engineering,  
LMSD (Mecha(tro)nic System Dynamics)  
Celestijnenlaan 300 - box 2420,  
B-3001 Heverlee, Belgium  
[ImSD@kuleuven.be](mailto:ImSD@kuleuven.be)

# KEYNOTE PAPERS

---

## KEY

### Session Keynote

Signal processing in mechanical engineering: a historical perspective and current challenges 1

J. Antoni

INSA Lyon, France

Shaping vibration engineering for the automotive transformation 12

C. Dindorf, N. Pandiya, A. Schmidt

Robert Bosch GmbH, Germany

# ISMA2024 PAPERS

---

## AVC

### Session Active Vibration Control

- Reduction of root loads due to gusts via active hinged wing tip control 27  
J. Ellis, D. Balatti, H. Haddad Khodaparast, S. Jiffri, M. Friswell  
Swansea University, United Kingdom
- Decentralized feedback damping with distributed control applied to ducts and anechoic chambers 40  
A. Berkhoff  
University of Twente, The Netherlands
- Semi-active control of modal energy transfer by means of lockable joints: theory and applications 55  
M. Ostrowski, B. Blachowski, G. Mikułowski, Ł. Jankowski  
Institute of Fundamental Technological Research of the Polish Academy of Sciences, Poland
- Semi-active control of modal energy transfer by means of lockable joints: experimental verification 70  
G. Mikułowski, M. Ostrowski, B. Blachowski, Ł. Jankowski  
Polish Academy of Sciences, Poland
- Exploiting fluid nonlinearity for sound control and sensing with parametric speakers 84  
I. Bucher, M. Friedlander, E. Uzhansky  
Technion, Israel
- Active vibration control of cable-driven parallel robots 93  
T. Garcia, D. Rémond, S. Chesné  
INSA Lyon, France
- Damage detection in a semi-active structural control system based on reinforcement learning 108  
A. Jedlińska, D. Pisarski, G. Mikułowski, B. Blachowski, Ł. Jankowski  
Polish Academy of Sciences, Poland
- Integration of active control with a compound acoustic black hole 118  
J. Cheer, L. Singleton, J. Tan  
University of Southampton, United Kingdom
- Comparison of feedback and feedforward active noise control concepts in an application with a partially open window 128  
T. Karl, D. Sachau  
Helmut Schmidt University Hamburg, Germany
- An investigation into the combination of passive acoustic treatments and active structural acoustic control 142  
C. Nikolaou, J. Cheer, F. Langfeldt  
University of Southampton, United Kingdom

Comparison of neural network architectures for feedforward active control of nonlinear systems	157
X. Pike, J. Cheer University of Southampton, United Kingdom	
On a new methodology for adaptive sliding mode control with self-tuning threshold: application to active vibration control	169
J. Rodriguez, A. Carvalho, S. Chesné INSA Lyon, France	
Active metamaterial cell for nonreciprocal sound transmission	179
S. Arandia-Krešić, N. Alujević, N. Mikšik, F. Ç. Bolat University of Zagreb, Croatia	
Data-driven nonlinear restoring force identification using Gaussian Process regression model for feedback linearization	191
J. Paixão, A. Platzer, J. Rodriguez, N. Blal, S. Baguet Université de Lyon, France	
Adaptive mitigation of unknown dynamic excitation using pneumatic damper with proportional piezoelectric valve	203
R. Faraj, G. Mikułowski, R. Wiszowaty, C. Graczykowski Polish Academy of Sciences, Poland	
On the stop band adaptivity range of locally resonant metamaterial resonators with piezoelectric patches: a case study	218
S. Janssen <sup>(1,2)</sup> , C. S. Schmidt <sup>(3)</sup> , L. P. R. de Oliveira <sup>(3)</sup> , C. De Marqui Junior <sup>(3)</sup> , C. Claeys <sup>(2,4)</sup> , E. Deckers <sup>(1,2)</sup>	
(1) KU Leuven Campus Diepenbeek, Belgium	
(2) Flanders Make @ KU Leuven, Belgium	
(3) University of São Paulo, Brazil	
(4) KU Leuven, Belgium	

---

## AA

### Session Aeroacoustics and flow noise

Numerical aero-acoustic performance investigation of an axial fan with a bio-inspired structures design	233
A. Rapisarda <sup>(1,3)</sup> , L. Sangiuliano <sup>(3)</sup> , L. D'Alessandro <sup>(3)</sup> , N. M. Pugno <sup>(1,2)</sup>	
(1) University of Trento, Italy	
(2) Queen Mary University of London, United Kingdom	
(3) Phononic Vibes Srl, Italy	
Aeroacoustic measurements of a high-lift model with different slat track geometries	247
T. Arnoult <sup>(1)</sup> , R. Zamponi <sup>(1)</sup> , G. Glabeke <sup>(1)</sup> , T. Toulorge <sup>(2)</sup> , V. Jovanovic <sup>(2)</sup> , C. Schram <sup>(1)</sup> , P. Planquart <sup>(1)</sup>	
(1) Von Karman Institute for Fluid Dynamics, Belgium	
(2) Centre de Recherche en Aeronautique-Cenaero, Belgium	

---

**CAM**
**Session Characterisation, design and optimisation of Acoustic Materials**

Optimized multi-modal rotational resonators for enhanced sound insulation in metamaterial cross-laminated timber panels	261
D. Giannini, E. P. B. Reynders KU Leuven, Belgium	
A numerical study of a vibro -acoustic metamaterial with an embedded Helmholtz Resonator	275
K. Leung, F. Langfeldt University of Southampton, United Kingdom	
The influence of dataset generation on the performance of deep learning for AMM design	288
O. Ogun, H. J. Rice, J. Kennedy Trinity College Dublin, Ireland	
Tuning low-frequency sound absorption in anisotropic multilayered poroelastic media using analytical microstructure modelling	298
E. Lundberg <sup>(1,2)</sup> , H. Mao <sup>(2)</sup> , M. Gaborit <sup>(3)</sup> , B. P. Semeniuk <sup>(2)</sup> , R. Rumlper <sup>(2)</sup> , P. Goransson <sup>(2)</sup>	
(1) Volvo Construction Equipment, Sweden	
(2) KTH Royal Institute of Technology, Sweden	
(3) Laboratoire d'Acoustique de l'Université du Mans (LAUM), France	
Extraction of tortuosity of melamine foam from ultrasonic transmission measurements: experimental improvement	313
T. S. Gomez <sup>(1,2)</sup> , D. Jun <sup>(3)</sup> , J. Cuenca <sup>(4)</sup> , N. Sebaa <sup>(5)</sup> , L. De Ryck <sup>(4)</sup> , R. Armstrong <sup>(1)</sup> , E. Piana <sup>(2)</sup> , C. Glorieux <sup>(1)</sup>	
(1) KU Leuven, Belgium	
(2) University of Brescia, Italy	
(3) Brno University of Technology, Czech Republic	
(4) Siemens Digital Industries Software, Belgium	
(5) Ecole nationale supérieure des technologies avancées, Algeria	
An acoustic material with tortuous slits filled with fibres	323
M. Niedzielczyk <sup>(1)</sup> , M.-A. Galland <sup>(2)</sup> , T. G. Zieliński <sup>(1)</sup>	
(1) Polish Academy of Sciences, Poland	
(2) Ecole Centrale de Lyon, France	
Comparison of double-porosity sound absorbers made of sintered or glued powder grains	337
K. C. Opiela <sup>(1)</sup> , N. Dauchez <sup>(2)</sup> , T. Boutin <sup>(2)</sup> , F.-X. Bécot <sup>(3)</sup> , F. Chevillotte <sup>(3)</sup> , R. Venegas <sup>(4)</sup> , T. G. Zieliński <sup>(1)</sup>	
(1) Polish Academy of Sciences, Poland	
(2) Université de Technologie de Compiègne, France	
(3) MATELYS - Research Lab, France	
(4) University Austral of Chile, Chile	

Study of the effect of load on the vibro-acoustic behavior of Kelvin-cell foam Z. Cai <sup>(1)</sup> , H. Mao <sup>(2)</sup> , V. Henriquez <sup>(1)</sup> , F. Lucklum <sup>(1)</sup> (1) Technical University of Denmark, Denmark (2) KTH Royal Institute of Technology, Sweden	347
3D simulation of porous concrete sonic crystals for noise barrier applications N. Herrera-Leon <sup>(1)</sup> , L. Godinho <sup>(1)</sup> , P. Amado-Mendes <sup>(1)</sup> , J. Redondo <sup>(2)</sup> (1) University of Coimbra, Portugal (2) Universitat Politècnica de València, Spain	353
Acoustic absorption of panels made of agglomerated olive leaves with a polymer matrix I. Montava Belda, J. G. Segura Alcaraz, E. Sanchis Juliá, J. M. Gadea Borrell Universitat Politècnica de València, Spain	363

---

## CMRM

### Session Condition monitoring of rotating machinery

Rotor state monitoring in full-scale industrial turbomachinery using component-based transfer path analysis D. Xu <sup>(1)</sup> , L. Renson <sup>(2)</sup> , C. Schwingshackl <sup>(2)</sup> (1) Technical University of Munich, Germany (2) Imperial College London, UK	368
Using rotary encoder signals for rotary vector reducer cycloidal gear fault detection Y. Guo, J. Y. Zhang Kunming University of Science and Technology, China	383
Development of a first-level nonintrusive acoustical method for health monitoring of hydroelectric generators M. Kirouac, K. Venne, A. Merkhouf Hydro-Québec, Canada	391
Harmonic-percussive source separation for fault detection in ball bearings characterized by cyclic polynomial motion law F. Pancaldi, G. D'Elia, M. Cocconcelli University of Modena and Reggio Emilia, Italy	405
Pseudo-cyclostationarity of bearing IAS signals: cage resynchronisation & synchronous averaging A. Marsick <sup>(1,2,3)</sup> , H. Andre <sup>(3)</sup> , I. Khelf <sup>(2)</sup> , L. Alloin <sup>(2)</sup> , Q. Leclere <sup>(1)</sup> , J. Antoni <sup>(1)</sup> (1) INSA Lyon, France (2) Engie Green, France (3) Université Jean Monnet Saint-Etienne, France	413
Rolling element bearing diagnostics using Fiber Bragg Grating sensors P. Mantas <sup>(1,2)</sup> , A. R. Mauricio <sup>(1,2)</sup> , S. F. Goossens <sup>(3,4)</sup> , D. S. Ojo <sup>(3,4)</sup> , F. Berghmans <sup>(3,4)</sup> , K. Gryllias <sup>(1,2)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium (3) Vrije Universiteit Brussel, Belgium (4) Flanders Make @ VUB, Belgium	427

Angular dynamic model of rotor-bearing-casing interaction for radial contact bearing monitoring	441
A. Burel <sup>(1,2)</sup> , N. Thibault <sup>(2)</sup> , A. Bourdon <sup>(1)</sup> , D. Lecouvreur <sup>(2)</sup> , N. Neveux <sup>(3)</sup> , D. Remond <sup>(1)</sup>	
(1) Université de Lyon, France	
(2) Safran Helicopter Engines, France	
(3) AlstomTransport, France	
Bearing diagnostics in high speed applications	456
W. Smith <sup>(1)</sup> , P. Borghesani <sup>(1)</sup> , R. Randall <sup>(1)</sup> , J. Antoni <sup>(1,2)</sup> , M. El Badaoui <sup>(3)</sup> , Z. Peng <sup>(1)</sup>	
(1) University of New South Wales, Australia	
(2) INSA Lyon, France	
(3) Safran Tech, France	
An algorithm based on digital twin sets of solutions for rolling-element bearing prognostics	471
A. Gabrielli <sup>(1)</sup> , M. Battarra <sup>(2)</sup> , E. Mucchi <sup>(2)</sup> , G. Dalpiaz <sup>(2)</sup>	
(1) MechVib Engineering S.r.l., Italy	
(2) University of Ferrara, Italy	
On the potential of bearing strain signals for defect severity estimation: modeling and experiments	484
E. Maljaars <sup>(1)</sup> , J. Ravesloot <sup>(1)</sup> , A. C. F. Janssen <sup>(1,2)</sup> , H. A. Mol <sup>(1)</sup> , C. G. Murguia <sup>(2)</sup> , R. H. B. Fey <sup>(2)</sup>	
(1) SKF B.V., The Netherlands	
(2) Eindhoven University of Technology, The Netherlands	
Remaining useful life prediction of bearings under steady and varying operating conditions using digital twin-based deep learning	493
S. A. Hosseinli <sup>(1,2)</sup> , T. Ooijevaar <sup>(3)</sup> , K. Gryllias <sup>(1,2)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make @ KU Leuven, Belgium	
(3) Flanders Make vzw, Belgium	
Development and evaluation of vibration indicators for gear pitting detection	508
R. Zhu <sup>(1,2)</sup> , D. V. Maele <sup>(3,5)</sup> , J. C. Poletto <sup>(3,4,5)</sup> , P. D. Baets <sup>(3,5)</sup> , K. Gryllias <sup>(1,2)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make@KU Leuven, Belgium	
(3) Ghent University, Belgium	
(4) Federal University of Rio Grande do Sul, Brazil	
(5) Flanders Make@UGent, Belgium	
Advanced diagnostic methods for bearings in wind turbine: indicators analysis and hyperparameters automation	522
S. E. Kramti <sup>(1,2)</sup> , H. André <sup>(1)</sup> , M. Sayadi <sup>(2)</sup> , M. El Badaoui <sup>(1)</sup>	
(1) Université Jean Monnet de Saint-Etienne, France	
(2) University of Tunis, Tunisia	
Bispectral analysis of envelopes – a very efficient algorithm for detecting cyclo-stationary components under noise	537
A. Trapp, D. Schmidt, S. Wokusch	
Siemens Mobility GmbH, Germany	

Statistical test for cyclostationarity based on CSC-based indicators - application to vibration signals from electric motor	551
A. Michalak <sup>(1)</sup> , J. Hebda-Sobkowicz <sup>(1)</sup> , J. Wodecki <sup>(1)</sup> , M. Dybkowski <sup>(2)</sup> , M. Wolkiewicz <sup>(1)</sup> , S. Weisse <sup>(2)</sup> , J. Valire <sup>(2)</sup> , K. Szabat <sup>(1)</sup> , R. Zimroz <sup>(1)</sup> , A. Wylomanska <sup>(1)</sup>	
(1) Wroclaw University of Science and Technology, Poland	
(2) SAFRAN Electrical & Power, France	
Comparative analysis of vibration and angular speed signals using synchronized data acquisition for bearing fault detection	566
J. Matthys <sup>(1,2)</sup> , C. Peeters <sup>(1,2)</sup> , G. Protopapadakis <sup>(1,2)</sup> , J. Sterckx <sup>(1,2)</sup> , J. Helsen <sup>(1,2)</sup>	
(1) Vrije Universiteit Brussel, Belgium	
(2) Flanders Make @ VUB, Belgium	
A novel simulation method for encoder signals in IAS monitoring applications	580
Z. Chu <sup>(1)</sup> , M. Luo <sup>(2)</sup> , F. Guillet <sup>(1)</sup> , H. Andre <sup>(1)</sup>	
(1) Univ Lyon, France	
(2) Chongqing University of Posts and Telecommunications, China	
Exploiting Non-Gaussian distributions in Hidden Markov Model for bearing prognostics	591
A. Lucchese, G. D'Elia, R. Rubini, M. Cocconcelli	
University of Modena and Reggio Emilia, Italy	
New health indicator based on robust spectral coherence maps for prognosis of degradation process in highly impulsive environment	601
W. Zulawinski <sup>(1)</sup> , D. Kuzio <sup>(2)</sup> , R. Zimroz <sup>(2)</sup> , A. Wylomanska <sup>(1)</sup>	
(1) Wroclaw University of Science and Technology, Faculty of Pure and Applied Mathematics, Poland	
(2) Wroclaw University of Science and Technology, Faculty of Geoengineering, Poland	
<hr/>	
<b>D</b>	
Session Damping	
Topology optimization of constrained layer damping on fan blades	616
M. Couet <sup>(1,2,3)</sup> , J.-F. Deü <sup>(1)</sup> , L. Rouleau <sup>(1)</sup> , F. Thouverez <sup>(2)</sup> , M. Gruin <sup>(3)</sup>	
(1) Conservatoire National des Arts et Métiers, France	
(2) Ecole Centrale de Lyon, France	
(3) Safran Aircraft Engines, France	
A simple predictive method for evaluating damping from thin viscoelastic layers in structures	627
F. Terzioglu, J. A. Rongong	
The University of Sheffield, United Kingdom	
Nonlinear dynamic properties of powders in additively manufactured steel beams	641
J. Black, S. Clawson, M. Allen, N. Crane, T. Nelson	
Brigham Young University, United States of America	

---

Non-linear viscoelastic damping: designing tests needed for transient simulation of a rail track	653
E. Balmes <sup>(1,2)</sup> , G. Martin <sup>(2)</sup> , O. Vo Van <sup>(3)</sup>	
(1) Arts et Metiers ParisTech, France	
(2) SDTools, France	
(3) SNCF DTIPG, France	
The importance of damping in nonlinear gear meshing simulations	665
F. Bruzzone <sup>(1,2)</sup> , C. Rosso <sup>(1,2)</sup>	
(1) Politecnico di Torino, Italy	
(2) GeDy TrAss s.r.l., Italy	
Vibration attenuation in AESA radar transmit/receive module via particle damping: an experimental study	675
S. Kumar, A. Kumar	
IIT Roorkee, India	
Tunable suspension stiffness through thermally controlled polymers	685
J. Roberjot <sup>(1,3)</sup> , E. Sadoulet-Reboul <sup>(1)</sup> , G. Chevallier <sup>(1)</sup> , N. Peyret <sup>(2)</sup> , K. Jaboviste <sup>(1)</sup> , C. Arnould <sup>(3)</sup> , E. Collard <sup>(3)</sup> , E. Bachy <sup>(3)</sup>	
(1) Université de Franche-Comté, France	
(2) ISAE-Supméca, France	
(3) Thales LAS, France	

---

## DET

Session Dynamic environmental testing

Real-time virtual shaker testing using an executable digital twin	694
M. Dal Borgo, U. Musella, L. Thielemans, S. Vettori, A. G. de Miguel, R. Pastorino, E. Di Lorenzo, B. Peeters	
Siemens Industry Software NV, Belgium	
Possible advantages to using a force-controlled MIMO test method for free-flight environments	704
R. Schultz, S. Carter	
Sandia National Laboratories, United States of America	
Understanding fixture design in IMMATs through FEM simulations	715
M. Behling <sup>(1)</sup> , M. Allen <sup>(1)</sup> , R. Mayes <sup>(2)</sup> , W. DeLima <sup>(3)</sup>	
(1) Brigham Young University, United States of America	
(2) Mayes Consulting, United States of America	
(3) Honeywell Federal Manufacturing & Technologies, United States of America	
Resonant plate shock test response with isolated damping bars	728
D. Soine	
Sandia National Laboratories, United States of America	
Optimization of irregular-shaped resonant plates for pyroshock testing in the aerospace industry	740
L. Viale, A. P. Daga, A. Fasana, L. Garibaldi	
Politecnico di Torino, Italy	

Fast evaluation of kurtosis and skewness by modal decomposition for fatigue analysis in frequency domain under non-Gaussian random loads M. Palmieri <sup>(1)</sup> , F. Cianetti <sup>(1)</sup> , J. Slavič <sup>(2)</sup> , C. Braccesi <sup>(1)</sup> (1) University of Perugia, Italy (2) University of Ljubljana, Slovenia	749
Multiaxial test-tailored vibration specifications: process overview M. Aimé <sup>(1)</sup> , A. Banvillet <sup>(1)</sup> , L. Khalij <sup>(2)</sup> , E. Pagnacco <sup>(2)</sup> , E. Chatelet <sup>(3)</sup> , R. Dufour <sup>(3)</sup> (1) CEADAM, France (2) INSA Rouen Normandie, France (3) Univ Lyon, France	757
Multi-axis shock and vibration control testing of automotive battery packs: challenges of an innovative testing practice A. Garcia de Miguel <sup>(1)</sup> , R. Araujo <sup>(1,2)</sup> , U. Musella <sup>(1)</sup> , M. dal Borgo <sup>(1)</sup> , B. Forrier <sup>(1)</sup> , E. di Lorenzo <sup>(1)</sup> , B. Cornelis <sup>(1)</sup> (1) Siemens Industry Software NV, Belgium (2) KU Leuven, Belgium	769
Using multi-shaker force control methods in modal analysis S. P. Carter, D. Rohe Sandia National Laboratories, United States of America	781
A novel MIMO random control strategy for efficient response replication at the component level E. Proner, E. Mucchi University of Ferrara, Italy	796
Development of multiaxial vibration test systems for small objects F. Decobert, S. Faye, L. Bemol SEREME, France	807
<hr/>	
<b>DT</b>	
Session Dynamic testing: methods and instrumentation	
Non-contact measurement of haptic systems J. A. Case <sup>(1)</sup> , A. Barnard <sup>(2)</sup> , A. Taggart <sup>(3)</sup> (1) Penn State, USA (2) Penn State, USA (3) PCB Piezotronics, USA	820
Database-supported correlation of modal data - the DLR correlation tool R. Buchbach, J. Sinske, Y. Govers, M. Böswald German Aerospace Center, Germany	830
Comparison of fundamental natural modes of cantilevered beam obtained by 3D X-ray computed tomography and laser Doppler vibrometry M. Machacek, S. Hračov, D. Vavřík, V. Rada The Institute of Theoretical and Applied Mechanics, Czech Republic	842

---

Thermal fluctuations of nano cantilevers for the detection of the biological particles modifications	852
E. Pierro <sup>(1)</sup> , G. Carbone <sup>(2)</sup>	
(1) University of Basilicata, Italy	
(2) Polytechnic University of Bari, Italy	
Developing methods for single-axis base excitation vibration testing with additional distributed shakers	860
S. M. Danforth, S. M. Johnson, K. F. Fenstermacher, A. J. Ramirez, H. R. Sedillo, J. F. Schultze, E. W. Ferguson	
Los Alamos National Laboratory, United States of America	
A new poly-reference complex frequency-domain identification technique formulated in state-space model	872
S. Diord Rescinho Amador <sup>(1)</sup> , J. Cara <sup>(2)</sup> , J. Bienert <sup>(3)</sup>	
(1) Technical University of Denmark, Denmark	
(2) Universidad Politécnica de Madrid, Spain	
(3) Technical University of Ingolstadt, Germany	
Distributed load and full-field response reconstruction during wind tunnel testing of an aluminum wing	884
S. Vettori <sup>(1)</sup> , D. Mastrodicasa <sup>(1,2)</sup> , A. Sosa Chavez <sup>(3)</sup> , A. Laurini <sup>(3)</sup> , E. Di Lorenzo <sup>(1)</sup> , K. Janssens <sup>(1)</sup>	
(1) Siemens Digital Industries Software, Belgium	
(2) Vrije Universiteit Brussel, Belgium	
(3) University of Rome “La Sapienza”, Italy	
Model-based approach to enhance CVT pushbelt testing and product performance	898
A. Maressa <sup>(1,2)</sup> , R. van Hoek <sup>(1)</sup> , P. van der Voort <sup>(1)</sup> , Q. H. V. Nguyen <sup>(1)</sup>	
(1) Bosch Transmission Technology, The Netherlands	
(2) TMC Italia (TMC Mechanical), Italy	
Frequency-domain estimation of acoustic and vibro-acoustic responses using transmissibility functions and few sensors	913
J. T. T. Nunes <sup>(1)</sup> , H. Policarpo <sup>(1,2)</sup> , M. M. Neves <sup>(1)</sup> , N. M. M. Maia <sup>(1)</sup>	
(1) Universidade de Lisboa, Portugal	
(2) Instituto Universitário Militar, Portugal	
Industrial application of residual power method as co-simulation performance indicator for e-motor hybrid-physical-virtual test setup	926
L. Thielemans <sup>(1,2)</sup> , B. H. C. Spath <sup>(1)</sup> , R. Pastorino <sup>(1)</sup> , W. Desmet <sup>(2,3)</sup> , J. Swevers <sup>(2,3)</sup>	
(1) Siemens Industry Software, Belgium	
(2) KU Leuven, Belgium	
(3) Flanders Make @ KU Leuven, Belgium	
Participation factor based identification of mode shapes	941
M. Donderer <sup>(1)</sup> , A. Rieß <sup>(2)</sup> , U. Waldenmaier <sup>(1)</sup> , J. Neher <sup>(3)</sup> , S. Ehlers <sup>(4)</sup>	
(1) MAN Energy Solutions SE, Germany	
(2) Technical University of Applied Sciences Augsburg, Germany	
(3) University of Applied Sciences Ulm, Germany	
(4) Hamburg University of Technology, Germany	

Theoretical and experimental modal analysis applied to the arterial system of the human body	952
F. Brunmayr, G. Mikota Johannes Kepler University, Austria	
Impulsive event detection: marine and lacustrine ice fracturing	967
J. A. Case, A. Barnard Penn State, USA	
AR-based setup of vibration sensors in test rigs	976
E. Ch. Ullrich <sup>(1)</sup> , D. Döbler <sup>(1)</sup> , P. Schmidt <sup>(1)</sup> , C. Canberk <sup>(2)</sup> (1) GFaI e.V. Signal Processing, Germany (2) gfai tech, Germany	
The influence of a static axial preload on the vibrational behaviour of a viscoelastic beam: an experimental assessment	982
E. Pierro <sup>(1)</sup> , D. Grillo <sup>(2)</sup> , G. Carbone <sup>(2)</sup> (1) University of Basilicata, Italy (2) Polytechnic University of Bari, Italy	
On the excitation of a lightweight and low mass structure	991
T. Knechten Siemens Industry Software NV, Belgium	
Sensor calibration procedure in high frequency range using laser Doppler vibrometer	1004
S. Lim, U. Woellner, A. Suglob Carl Zeiss SMT GmbH, Germany	
Mode indicator guided sequential modal analysis.	1012
C. O. Ogbodo <sup>(1)</sup> , T. J. Rogers <sup>(1)</sup> , M. Dal Borgo <sup>(2)</sup> , D. J. Wagg <sup>(1,3)</sup> (1) University of Sheffield, UK (2) Siemens Industry Software NV, Belgium. (3) The Alan Turing Institute, UK.	
On the probability density function of rainflow stress range for sine on random processes	1023
G. Zucca <sup>(1,2)</sup> , M. Palmieri <sup>(2)</sup> , C. Braccesi <sup>(2)</sup> , F. Cianetti <sup>(2)</sup> (1) Italian Air Force, Italy (2) University of Perugia, Italy	

---

## JOINT

### Session Dynamics of Joints

Superharmonic resonances and model validation with the Half Brake-Reuss Beam	1035
J. H. Porter, M. R. Brake Rice University, United States of America	

A new distributed joint model for non-ideal supports in curved panels under large-amplitude vibrations	1042
H. Farokhi <sup>(1)</sup> , N. Jamia <sup>(2)</sup> , H. Jalali <sup>(1)</sup> , J. Taghipour <sup>(2,3)</sup> , H. Haddad Khodaparast <sup>(2)</sup> , M. I. Friswell <sup>(2)</sup>	
(1) Northumbria University, UK	
(2) Swansea University, UK	
(3) Dyson Institute of Engineering and Technology, UK	
Experimental analysis of dynamic characteristics in bolted joint interfaces of thin plates	1051
N. Jamia <sup>(1)</sup> , P. Pandey <sup>(1)</sup> , H. Farokhi <sup>(2)</sup> , M. I. Friswell <sup>(1)</sup> , H. Haddad Khodaparast <sup>(1)</sup> , H. Jalali <sup>(2)</sup>	
(1) Swansea university, UK	
(2) Northumbria University, UK	
Dual substructure decoupling for joint identification with unmeasurable interface: a comparative study	1066
J. Brunetti <sup>(2)</sup> , W. D'Ambrogio <sup>(2)</sup> , M. Di Manno <sup>(1)</sup> , A. Fregolent <sup>(1)</sup> , M. Ialonardi <sup>(1)</sup>	
(1) Università degli studi di Roma La Sapienza, Italy	
(2) Università degli studi dell'Aquila, Italy	
Training artificial neural networks using substructuring techniques: application to joint identification	1081
J. Korbar, D. Ocepek, M. Boltežar, G. Čepon	
University of Ljubljana, Slovenia	
On the experimental linear identification of a multiple-joint bolted connection using frequency-based substructuring	1096
M. Kreutz, F. Trainotti, D. J. Rixen	
Technical University of Munich, Germany	

---

## RMD

### Session Dynamics of Rotating Machinery

Electromagnetic shunt damping for torsional vibration reduction in rotating structures: theory, optimization, and experimental insights	1110
G. Hay <sup>(1)</sup> , C. Giraud-Audine <sup>(1)</sup> , H. Mahé <sup>(2)</sup> , O. Thomas <sup>(1)</sup>	
(1) Arts et Métiers Institute of Technology, France	
(2) Valeo, France	
On the numerical modelling of a rotor system to support the analysis of experimental vibration signals for the condition monitoring of a CN lathe integrated with an automatic bar feeder	1125
L. Caselli <sup>(1)</sup> , M. Rizzitelli <sup>(2)</sup> , A. Rivola <sup>(1)</sup> , M. Troncosi <sup>(1)</sup>	
(1) University of Bologna, Italy	
(2) IEMCA – a Bucci Automations S.p.A. Division, Italy	
Investigation of large, air-cooled condenser drive-train torque oscillations during startup	1137
D. N. J. Els, M. P. Venter	
Stellenbosch University, South Africa	

---

Experimental validation of the linear transducer model of permanent magnet synchronous motors for torsional vibration analysis applications T. A. Kimpíán <sup>(1)</sup> , F. Augusztnovicz <sup>(2)</sup> (1) thyssenkrupp Components Technology Hungary Ltd., Hungary (2) Budapest University of Technology and Economics, Hungary	1150
Modelling mechanical faults in induction motors using magnetic equivalent circuits and lumped-element shaft-bearing dynamics P. Desenfans <sup>(1)</sup> , Z. Gong <sup>(1)</sup> , D. Vanoost <sup>(1)</sup> , K. Gryllias <sup>(1,2)</sup> , D. Pissort <sup>(1)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium	1165
Extraction of the rotor dynamic behavior on a flexible support structure by dynamic substructuring V. M. Martini, E. P. Okabe, K. L. Cavalca Universidade Estadual de Campinas (UNICAMP), Brazil	1179
Cutting torque model for patient - specific pedicle screw surgical simulators A. Syamlan, K. Denis, E. Vander Poorten, T. Tjahjowidodo KU Leuven, Belgium	1194
Analysis of rotor-bearing systems utilising fractional derivative material damping models G. Überwimmer, M. Klanner, K. Ellermann Graz University of Technology, Austria	1206
Modelling and tuning of a permanent magnetic suspension system for low-vibration flywheels M. Baekeland <sup>(1)</sup> , C. Cuypers <sup>(2)</sup> , T. Delabie <sup>(2)</sup> , R. Seiler <sup>(3)</sup> , K. Gryllias <sup>(1,4)</sup> , D. Vandepitte <sup>(1)</sup> (1) KU Leuven, Belgium (2) arcsec, Belgium (3) ESA/ESTEC, The Netherlands (4) Flanders Make @ KU Leuven, Belgium	1219
Examining sliding in rotor assemblies: an experimental study N. Abuhemeida <sup>(1,2)</sup> , D. Vaillant <sup>(1)</sup> , G. Chevallier <sup>(2)</sup> , F. Cronfalt <sup>(1)</sup> , M. Topenot <sup>(1)</sup> , M. Ouisse <sup>(2)</sup> (1) Alstom Transport, France (2) Université de Franche-Comté, France	1234
Analyzing transient cutting behaviour of a cutter suction dredger drive train: enhancing operational efficiency through co-simulation L. Vancauwenbergh <sup>(1,2)</sup> , M. Verbist <sup>(1)</sup> , D. Vandepitte <sup>(1)</sup> , F. Naets <sup>(1)</sup> , D. Moens <sup>(1)</sup> , G. Vanneste <sup>(2)</sup> , S. Claessens <sup>(2)</sup> , P. M. Vercrijse <sup>(2)</sup> (1) KU Leuven, Belgium (2) DEME NV, Belgium	1243
Exact and an approximate solution for free vibrations of rotating cylindrical shells having both ends clamped R. Radoš, N. Alujević, N. Vladimir, S. Arandia-Krešić, I. Catipović University of Zagreb, Croatia	1259

Rattle detection in gearing systems by noise and vibration measurements G. Cristofori, E. Mucchi University of Ferrara, Italy	1274
Estimation of synchronous response of time-variant systems by rotated wavelet probing D. Iaffaldano <sup>(1)</sup> , R. Guida <sup>(2)</sup> , L. Carassale <sup>(1)</sup> (1) Università degli Studi di Genova, Italy (2) Ansaldo Energia, Italy	1284
Calculation of excitation forces generated by axial-flow fan system H. Ota <sup>(1,2)</sup> , T. Sato <sup>(1)</sup> , S. Niita <sup>(2)</sup> (1) Tokyo Denki University, Japan (2) Hitachi-Johnson Controls Inc., Japan	1294
Managing peak response as a rotor accelerates through a 'follower critical speed' R. Yorke, S. D. Garvey, M. Amoozgar University of Nottingham, United Kingdom	1305

---

## CIV

### Session Dynamics of civil structures

The use of strain-based unit influence lines for structural health monitoring of railway bridges K. Maes <sup>(1)</sup> , K. Verbist <sup>(1)</sup> , K. Berten <sup>(2)</sup> , E. Reynders <sup>(1)</sup> , G. Lombaert <sup>(1)</sup> (1) KU Leuven, Belgium (2) TUC Rail, Belgium	1320
Vibration-based condition assessment of concrete beams after fire loading E. Reynders <sup>(1)</sup> , J. Godeau <sup>(1,2)</sup> , B. Jovanović <sup>(1,2)</sup> , M. van de Velde <sup>(1)</sup> , J. Vastiau <sup>(1)</sup> , D. Anastasopoulos <sup>(1)</sup> , G. Lombaert <sup>(1)</sup> , R. Caspeele <sup>(2)</sup> , R. Van Coile <sup>(2)</sup> (1) KU Leuven, Belgium (2) UGent, Belgium	1332
Initial validation of a local structural dynamics monitoring system for smart buildings A. T. Gothard <sup>(1)</sup> , C. Wall <sup>(1)</sup> , R. C. Henderson <sup>(1)</sup> , S. R. Anton <sup>(1)</sup> , M. Cardinal <sup>(2)</sup> , A. Taggart <sup>(2)</sup> (1) Tennessee Tech University, USA (2) PCB Piezotronics, Inc., USA	1341
Finite element models for laminated timber structures using solid, solid-beam and solid-shell approaches J. Paroissien <sup>(1,2)</sup> , P. Lardeur <sup>(1)</sup> , M. Oudjene <sup>(2)</sup> (1) Université de technologie de Compiègne, France (2) Université Laval, Canada	1356
Monitoring and modeling of the vibratory behavior of high-rise timber building D. Janot <sup>(1)</sup> , F. Vieux-Champagne <sup>(1)</sup> , P. Gueguen <sup>(2)</sup> , C. Boudaud <sup>(3)</sup> (1) Université Grenoble Alpes, France (2) ISTERre, France (3) Ecole Supérieure du Bois et des Matériaux Biosourcés, France	1370

Data-driven approaches in modal analysis of building structures	1382
---	------

Y. Si <sup>(1)</sup>, Y. Zhu <sup>(2)</sup>, J. N. Kutz <sup>(3)</sup>, L. Cheng <sup>(1)</sup>

(1) University of Groningen, The Netherlands

(2) Queen Mary, University of London, UK

(3) University of Washington, USA

---

## GECKO

### Session GECKO session

Model order reduction of isogeometric BEM systems via Krylov subspace recycling	1395
---	------

P. Le <sup>(1,2)</sup>, D. Panagiotopoulos <sup>(1,2)</sup>, E. Deckers <sup>(1,2)</sup>

(1) KU Leuven, Belgium

(2) Flanders Make @ KU Leuven, Belgium

Application of the isogeometric shifted boundary method to the Poisson problem	1407
--	------

N. Antonelli <sup>(1,2)</sup>, A. Gorgi <sup>(1,2)</sup>, R. Aristio <sup>(3)</sup>, R. Zorrilla <sup>(1,2)</sup>, R. Rossi <sup>(1,2)</sup>, G. Scovazzi <sup>(4)</sup>, R. Wüchner <sup>(3)</sup>

(1) Universitat Politècnica de Catalunya, Spain

(2) International Center for Numerical Methods in Engineering (CIMNE), Spain

(3) Technische Universität Braunschweig, Germany

(4) Duke University, USA

Immersed IGA and mass lumping for explicit dynamics of 1D structural elements	1420
---	------

A. Pagonas <sup>(1)</sup>, L. Radtke <sup>(2)</sup>, M. Torre <sup>(1)</sup>, T. J. R. Hughes <sup>(3)</sup>, A. Düster <sup>(2)</sup>, G. Sangalli <sup>(4)</sup>, A. Reali <sup>(1)</sup>

(1) Università di Pavia, Italy

(2) Hamburg University of Technology, Germany

(3) University of Texas at Austin, USA

(4) Università di Pavia, Dipartimento di Matematica, Italy

---

## INV

### Session Inverse Methods - Load Identification

Lumped parameter modelling rubber bushing dynamics in free-free boundary condition	1430
--	------

W. Trekels <sup>(1)</sup>, J. Staiger <sup>(1,2)</sup>, J. del Fresno Zarza <sup>(1,2)</sup>, F. Naets <sup>(1,2)</sup>

(1) KU Leuven, Belgium

(2) Flanders Make @ KU Leuven, Belgium

Cutting force estimation in metal cutting tools: a study on a sensor-equipped cantilever beam	1445
---	------

P. Wu <sup>(1,2)</sup>, M. Magnevall <sup>(2)</sup>, A. Liljerehn <sup>(1)</sup>, D. Östling <sup>(1)</sup>

(1) AB Sandvik Coromant, Sweden

(2) Blekinge Institute of Technology, Sweden

Modal analysis of metallic structures filled with elastomer and inverse identification of material parameters	1457
---	------

M. Marion <sup>(1,2)</sup>, B. Lossouarn <sup>(1)</sup>, L. Rouleau <sup>(1)</sup>, A. Voisin <sup>(2)</sup>, C. Leblond <sup>(2)</sup>, J.-F. Deü <sup>(1)</sup>

(1) Conservatoire National des Arts et Métiers, France

(2) Naval Group, France

Algebraic k-space identification 2D technique for the automatic extraction of complex k-space of 2D structures in presence of uncertainty	1471
T. Brion <sup>(1)</sup> , X. Li <sup>(1,2)</sup> , P. Fossat <sup>(1)</sup> , M. Ichchou <sup>(1)</sup> , O. Bareille <sup>(1)</sup> , A.-M. Zine <sup>(1)</sup>	
(1) Ecole Centrale de Lyon, France	
(2) KTH Royal Institute of Technology, Sweden	
Application of an augmented Kalman filter to the inverse identification of aerodynamic loads on a road vehicle	1485
S. Reymert, Ø. Wiig Petersen	
Norwegian University of Science and Technology, Norway	
Force virtual sensing applied to a structure excited by an inertial shaker	1495
B. Mora <sup>(1)</sup> , J. Basurko <sup>(1)</sup> , I. Sabahi <sup>(2,3)</sup>	
(1) Ikerlan Technology Research Centre, Spain	
(2) KU Leuven, Belgium	
(3) Flanders Make@KU Leuven, Belgium	
Characterization of thermal elastic moduli of anisotropic lattice metamaterials: designing dual-functional metamaterials with low thermal expansion and vibration mitigation capabilities	1510
H. Mao <sup>(1)</sup> , A. Holmén <sup>(1)</sup> , B. Yin <sup>(3)</sup> , R. Rumpler <sup>(1,2)</sup> , G. Tibert <sup>(1)</sup> , P. Göransson <sup>(1,2)</sup>	
(1) KTH Royal Institute of Technology, Sweden	
(2) Marcus Wallenberg Laboratory for Sound and Vibration Research, Sweden	
(3) Zhejiang University, China	
A tomographic method to predict forces in a rolling element bearings	1518
J. J. Kent, M. De Carvalho Loures, A. L. Gower	
University of Sheffield, United Kingdom	
Enhancing road roughness identification and system observability through measurement strategies in vehicle dynamics	1530
A. Leanza, S. De Carolis, G. Carbone, L. Soria	
Politecnico di Bari, Italy	
Dynamics of a cantilever beam under the effect of the water droplet impact	1541
J. Taghipour, M. H. Biroun	
Dyson Institute of Engineering and Technology, United Kingdom	

---

## LW

### Session Lightweight Structures and Materials

Pitfalls in shaker vibration tests on lightweight structures	1553
C. Schedlinski	
ICS Engineering GmbH, Germany	
Determination of the equivalent mechanical parameters of honeycomb sandwich structures under the algebraic identification framework	1568
X. Li <sup>(1,2)</sup> , H. Mao <sup>(1)</sup> , M. Ichchou <sup>(2)</sup> , R. Rumpler <sup>(1)</sup> , P. Göransson <sup>(1)</sup>	
(1) KTH Royal Institute of Technology, Sweden	
(2) École Centrale de Lyon, France	

Experimental analysis of passive damping techniques applied to a cantilever beam using piezoelectric patches and constrained layer damping	1578
M. Melero, A. J. Nieto, A. L. Morales, J. Jimenez, C. Ramiro, P. Pintado Universidad de Castilla-La Mancha, Spain	
Holistic approach to vibration characterisation of large structural components in thermal environment	1586
P. Hüttich, D. Krause Hamburg University of Technology, Germany	

---

## MOIRA

### Session MOIRA session

Bayesian convolutional neural network models for uncertainty-aware bearing fault detection	1600
a. mostafavi <sup>(1,2)</sup> , A. Friedmann <sup>(1)</sup> (1) Fraunhofer Institute, Germany (2) Technische Universität Darmstadt, Germany	
Data-efficient fault detection in vehicle end-of-line testing through fault location-informed classification	1612
D. S. Kunte <sup>(1,2)</sup> , D. G. Marx <sup>(2,3)</sup> , B. Cornelis <sup>(1)</sup> , C. Colangeli <sup>(1)</sup> , K. Gryllias <sup>(2,3,4)</sup> (1) Siemens Digital Industries Software NV, Belgium (2) KU Leuven, Belgium (3) Flanders Make @ KU Leuven, Belgium (4) Leuven.AI - KU Leuven Institute for AI, Belgium	
Validation of time series anomaly detection methods for automated detection of measurement anomalies in noise and vibration testing	1625
L. Jia <sup>(1)</sup> , B. Cornelis <sup>(1)</sup> , K. Gryllias <sup>(2,3,4)</sup> (1) Siemens Industry Software NV, Belgium (2) KU Leuven, Belgium (3) Flanders Make @ KU Leuven, Belgium (4) Leuven.AI - KU Leuven Institute for AI, Belgium	
Robust remaining useful life prediction from time-varying health index data in presence of heavy-tailed noise	1640
H. Shiri, P. Zimroz, A. Wylomanska, R. Zimroz Wroclaw University of Science and Technology, Poland	
A method for adding domain knowledge to semi-supervised fault detection using signal processing gradients	1655
D. Marx <sup>(1,2)</sup> , D. Kunte <sup>(1,3)</sup> , B. Cornelis <sup>(3)</sup> , K. Gryllias <sup>(1,2,4)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium (3) Siemens Digital Industries Software NV, Belgium (4) Leuven.AI - KU Leuven Institute for AI, Belgium	
Characterization and identification of nonlinear cyclic excitations in non-stationary gearbox operations	1672
M. Ahani, A. Bourdon, D. Rémond Univ Lyon, France	

A two-step synchrosqueezing transform approach mitigating reallocation errors in time-frequency analysis	1685
F. Karkafi <sup>(1,2)</sup> , M. Leiber <sup>(1)</sup> , Q. Leclère <sup>(2)</sup> , J. Antoni <sup>(2)</sup> , M. El Badaoui <sup>(1,3)</sup>	
(1) Safran Tech, France	
(2) INSA Lyon, France	
(3) UJM-St-Etienne, France	
Ball-bearings fault detection for an independent cart system: experimental campaign and preliminary results	1698
A. Jabbar, C. Fonte, G. D'Elia, M. Cocconcelli	
University of Modena and Reggio Emilia, Italy	
A vibration based self-learning approach for machine condition monitoring	1712
F. De Fabritiis <sup>(1,2)</sup> , K. Gryllias <sup>(1,2,3)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make @ KU Leuven, Belgium	
(3) Leuven.AI- KU Leuven Institute for AI, Belgium	
<hr/>	
<b>MOR</b>	
Session Model Order Reduction	
Vibration reduction design approach for motor-driven fans using piezoelectric actuators including identification, model order reduction and optimization	1727
X. Y. Ratke <sup>(1,2)</sup> , T. Sattel <sup>(1)</sup>	
(1) TU Ilmenau, Germany	
(2) ZIEHL-ABEGG SE, Germany	
A hybrid two-stage model order reduction and substructuring scheme involving Craig-Bampton method and balanced truncation	1742
L. Peri <sup>(1,3)</sup> , M. Pagano <sup>(1)</sup> , L. Dozio <sup>(1)</sup> , P. Nali <sup>(2)</sup>	
(1) Politecnico di Milano, Italy	
(2) Thales Alenia Space, Italy	
(3) KU Leuven, Belgium	
Structural model parameter identification: leveraging augmented kalman filtering and parametric reduced order models within an optimization scheme	1756
D. De Gregoriis <sup>(1)</sup> , F. Capurso <sup>(1)</sup> , O. Atak <sup>(2)</sup>	
(1) Siemens Industry Software NV, Belgium	
(2) Siemens Digital Industries Software, United Kingdom	
Non-intrusive parametric hyper-reduction for nonlinear structural finite elements formulations	1770
D. Fleres <sup>(1,2)</sup> , D. De Gregoriis <sup>(2)</sup> , O. Atak <sup>(2)</sup> , F. Naets <sup>(1,3)</sup>	
(1) KU Leuven, Belgium	
(2) Siemens Digital Industries Software, Belgium	
(3) Flanders Make @ KU Leuven, Belgium	
Harmonic balance based methodology for reduced order modeling to predict response of nonlinear structures	1785
M. Khan, B. R. Pacini, R. J. Kuether	
Sandia National Laboratories, United States of America	

A deep-learning approach for the identification of reduced order nonlinear dynamics	1797
K. Tatsis <sup>(1)</sup> , K. Agathos <sup>(2)</sup>	
(1) Swiss Data Science Center (SDSC), Switzerland	
(2) Exeter University, UK	

---

## MU

### Session Model Update

Hybrid FEM/test twin building, an electric engine case history	1805
E. Balmes <sup>(1,2)</sup> , G. Vermot des Roches <sup>(2)</sup> , S. Nacivet <sup>(3)</sup>	
(1) Arts et Metiers ParisTech, France	
(2) SDTools, France	
(3) Stellantis, France	
Effects of similarity measures and assignment methods on mode pairing for the application of timber plates	1813
B. Chocholaty <sup>(1)</sup> , C. Leiber <sup>(2)</sup> , S. Marburg <sup>(1)</sup>	
(1) Technical University of Munich, Germany	
(2) LMU Munich & MCML, Germany	
Identification of the modal and structural properties of a high-rise scale model	1828
A. J. Bronkhorst <sup>(1)</sup> , E. Marchelli <sup>(2)</sup> , D. Moretti <sup>(1)</sup> , K. Maes <sup>(3)</sup> , G. Lombaert <sup>(3)</sup>	
(1) TNO, The Netherlands	
(2) Università degli Studi di Genova, Italy	
(3) KU Leuven, Belgium	
Geometric parameter estimation of thin-walled structures using finite element model updating, shape optimisation and frequency response functions	1843
M. Kamper <sup>(1,2)</sup> , F. Naets <sup>(1,2)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make@KU Leuven, Belgium	
The role of the conditional network in data-driven stochastic model updating based on the conditional invertible neural network (cINN)	1858
T. Wang <sup>(1)</sup> , S. Bi <sup>(1)</sup> , J. E. Mottershead <sup>(2)</sup>	
(1) University of Southampton, United Kingdom	
(2) University of Liverpool, United Kingdom	

---

## MB

### Session Multi-body dynamics and control

A Kalman-based approach to drivetrain misalignment estimation	1871
L. Mazzanti <sup>(1,2,3)</sup> , M. Vivet <sup>(1,2)</sup> , D. De Gregoriis <sup>(1,2)</sup> , F. Naets <sup>(1,3)</sup>	
(1) KU Leuven, Belgium	
(2) Siemens Digital Industries Software, Belgium	
(3) Flanders Make @ KU Leuven, Belgium	
Effect of gear teeth elastic deformation on the gear mesh stiffness of parallel gearboxes	1884
B. El Yousfi <sup>(1)</sup> , A. Soualhi <sup>(2)</sup> , A. Lourari <sup>(1)</sup> , A. Bouzar Essaidi <sup>(1)</sup> , A. El Amli <sup>(2)</sup>	
(1) Ecole Militaire Polytechnique, Algeria	
(2) Université Jean Monnet de Saint Etienne, France	

---

Advanced practical gearbox NVH analyses: an engineering guide S. Schneider <sup>(1)</sup> , B. Graf <sup>(1)</sup> , E. Refik <sup>(1)</sup> , T. Giese <sup>(2)</sup> (1) Ulm University of Applied Sciences, Germany (2) FunctionBay GmbH, Germany	1893
Input-state estimation for multi-body dynamic systems with Bayesian filters A. Malund Dammark Jensen, M. Lund Thing, S. Gres, G. Abbiati Aarhus University, Denmark	1908
Refining gearbox multibody simulation: enhancements for NVH and acoustic analysis D. Werner <sup>(1)</sup> , G. Offner <sup>(2)</sup> , N. Lorenz <sup>(3)</sup> , C. Schweiger <sup>(2)</sup> (1) AVL Deutschland GmbH, Germany (2) AVL List GmbH, Austria (3) MathConsult GmbH, Austria	1923
Co-simulation approach integrating multibody and discrete element modeling for robomould process analysis M. Goris <sup>(1,2)</sup> , E. Deckers <sup>(1,2)</sup> , F. Naets <sup>(1,2)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium	1939
A python software development for dynamic simulation of mobile elevating work platform G. Cangini <sup>(1,2)</sup> , A. Angeletti <sup>(2)</sup> , M. Balducci <sup>(2)</sup> , M. Palmieri <sup>(1)</sup> , F. Cianetti <sup>(1)</sup> (1) University of Perugia, Italy (2) Terex Italia, Italy	1952
An iterative procedure to integrate elastodynamic simulations and virtual commissioning of mechatronic systems: a machine tool case-study P. Gioviti <sup>(1)</sup> , A. Martini <sup>(2)</sup> , F. Naets <sup>(3)</sup> , A. Rivola <sup>(2)</sup> , M. Troncossi <sup>(2)</sup> (1) GIULIANI – a Bucci Automations S.p.A. Division, Italy (2) University of Bologna, Italy (3) KU Leuven, Belgium	1964

---

## NL

### Session Non-linearities: identification and modelling

Prediction of limit cycle oscillations from aeroelastic test data J. Cooper University of Bristol, United Kingdom	1978
Optimal experimental design for modeling the dynamic response of a pseudo-static moving load on a beam J. K. Mikkelsen, L. D. Avendaño-Valencia, C. Schlette University of Southern Denmark, Denmark	1989

---

Vibration control of a mechanical system using a passive/semiactive flexible inverted pendulum vibration absorber H. F. Abundis-Fong <sup>(1)</sup> , L. G. Trujillo-Franco <sup>(2)</sup> , I. Gutierrez-Carmona <sup>(3)</sup> , A. E. Dzul-Lopez <sup>(4)</sup> (1) Tecnológico Nacional de México/I.T. Pachuca, Mexico (2) Instituto Politécnico Nacional, Mexico (3) Instituto Tecnológico y de Estudios Superiores de Monterrey, Mexico (4) Tecnológico Nacional de México/I.T. La Laguna, Mexico	2002
Regularising NARX models with multi-task learning S. C. Bee <sup>(1)</sup> , L. Bull <sup>(2)</sup> , N. Dervilis <sup>(1)</sup> , K. Worden <sup>(1)</sup> (1) University of Sheffield, United Kingdom (2) University of Cambridge, United Kingdom	2014
Unlocking the insights of dynamics through experimentation of an electric drive Z. G. Gazdag <sup>(1,2)</sup> , B. Fukker <sup>(1)</sup> , B. Vehovszky <sup>(2)</sup> (1) Robert Bosch Kft, Hungary (2) Széchenyi István University, Hungary	2022
Analysis of variability in machine tool dynamics through enhanced SMFE method A. Iglesias <sup>(1)</sup> , O. Franco <sup>(1)</sup> , X. Beudaert <sup>(1)</sup> , M. Sanz-Calle <sup>(1)</sup> , J. Munoa <sup>(1,2)</sup> (1) IDEKO, Spain (2) University of the Basque Country, Spain	2031
Data-driven state-space identification and nonlinearity assessment of the CubeSpec Fine Steering Mirror M. Floren <sup>(1,2)</sup> , L. Peri <sup>(1)</sup> , J. De Maeyer <sup>(1)</sup> , W. De Munter <sup>(1)</sup> , D. Vandepitte <sup>(1)</sup> , J.-P. Noël <sup>(1)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium	2042
Numerical models and stability analysis of control-based methods for nonlinear vibration testing G. Raze, T. Zhou University of Liège, Belgium	2053
Investigation of perfect curve fitting of spectra from linear and non-linear structures using barycentric interpolation H. Goyder Cranfield University, United Kingdom	2068
Nonlinear behaviours of a class of inertial amplifiers A. D. Shaw <sup>(1)</sup> , E. Nar <sup>(2)</sup> , S. Adhikari <sup>(3)</sup> (1) Swansea University, United Kingdom (2) University of Bristol, United Kingdom (3) University of Glasgow, United Kingdom	2081
Comparative study of nonlinear modal modeling identification techniques from force appropriation experiments B. R. Pacini, R. J. Kuether, D. Fowler Sandia National Laboratories, United States of America	2093

---

Convolutional neural networks applied to nonlinear dynamical systems: a Wiener series perspective	2108
J. Massingham <sup>(1)</sup> , O. Nielsen <sup>(1,2)</sup> , T. Butlin <sup>(1)</sup>	
(1) University of Cambridge, United Kingdom	
(2) Bose Corporation, United States of America	
Revisiting a link between algebraic geometry and nonlinear dynamics	2122
K. Worden	
University of Sheffield, United Kingdom	
Estimation of the periodic solutions of geometrically nonlinear structures by broadband excitation	2138
D. Anastasio <sup>(1)</sup> , S. Marchesiello <sup>(1)</sup> , G. Kerschen <sup>(2)</sup>	
(1) Politecnico di Torino, Italy	
(2) University of Liège, Belgium	
Exploring feasibility of neural networks for dynamic system with friction damping	2151
F. Cuccovillo, T. M. Berruti, D. Botto	
Politecnico di Torino, Italy	
Enhancing model selection for a nonlinear system: a physics-based machine learning approach	2161
J. Taghipour <sup>(1,3)</sup> , N. Ebrahimzade <sup>(2)</sup> , P. Pandey <sup>(3)</sup> , H. Haddad Khodaparast <sup>(3)</sup> , M. I. Friswell <sup>(3)</sup>	
(1) Dyson Institute of Engineering and Technology, UK	
(2) Dyson Technology Limited, UK	
(3) Swansea University, UK	
Nonlinear normal modes as normalising Kalman filters	2174
L. Bull <sup>(1,2)</sup> , T. Dardeno <sup>(3)</sup> , N. Dervilis <sup>(3)</sup> , A. Glyn-Davies <sup>(2)</sup> , J. Bunker <sup>(2)</sup> , M. Girolami <sup>(2,4)</sup> , K. Worden <sup>(3)</sup>	
(1) University of Glasgow, Scotland	
(2) University of Cambridge, UK	
(3) University of Sheffield, UK	
(4) The Alan Turing Institute, UK	
Damped nonlinear modes and forced response analysis of a system with hybrid nonlinearity	2188
F. Mashayekhi <sup>(1)</sup> , R. Alcorta <sup>(2)</sup>	
(1) Politecnico di Torino, Italy	
(2) INSA Lyon, France	
Numerical investigation of the aeroelastic response of a NACA0012-profile in flutter condition including cubic nonlinear stiffness using URANS based simulations	2203
A. C. G. Amaral <sup>(1,2)</sup> , W. De Roeck <sup>(1)</sup> , M. Silveira <sup>(2)</sup>	
(1) KU Leuven, Belgium	
(2) UNESP, Brazil	
Hybrid deep learning and frequency response function modelling for automotive testing	2213
T. Westmeier <sup>(1)</sup> , D. Kreuter <sup>(1)</sup> , S. Bucher <sup>(1)</sup> , H. Hetzler <sup>(2)</sup>	
(1) Robert Bosch GmbH, Germany	
(2) Universität Kassel, Germany	

---

Recent advances in control-based nonlinear vibration testing G. Raze, G. Abeloos, G. Kerschen University of Liege, Belgium	2224
GP-NARX for active control of nonlinear flexible structures N. A. AlQahtani, T. J. Rogers, N. D. Sims The University of Sheffield, United Kingdom	2239
Milling robot modal analysis using spindle-driven unbalanced excitation in context of its response nonlinearity G. Altshul <sup>(1)</sup> , M. Guskov <sup>(1)</sup> , E. Balmes <sup>(1,2)</sup> , P. Lorong <sup>(1)</sup> (1) PIMM, France (2) SDTools, France	2250
A reduced order approach for race car porpoising B. Bauer <sup>(1)</sup> , A. Papangelo <sup>(2)</sup> , G. Habib <sup>(1)</sup> (1) Budapest University of Technology and Economics, Hungary (2) Politecnico di Bari, Italy	2260
A resection algorithm for control-free shaker testing of weakly coupled smooth nonlinear systems Z. Gabos, Z. Dombovari Budapest University of Technology and Economics, Hungary	2271
Optimizing mass in mass metamaterials for enhanced energy harvesting: via analytical and machine learning approach P. Pandey <sup>(1)</sup> , S. Barman <sup>(2)</sup> , H. Haddad Khodaparast <sup>(1)</sup> , T. Mukhopadhyay <sup>(3)</sup> , H. Madineh <sup>(1)</sup> , S. Dey <sup>(2)</sup> , M. I. Friswell <sup>(1)</sup> (1) Swansea University, United Kingdom (2) National Institute of Technology, India (3) University of Southampton, United Kingdom	2279
Using higher-order frequency response functions from NARX models to support activation function choices O. H. L. Preston, T. J. Rogers, K. Worden University of Sheffield, United Kingdom	2294
Numerical detection of frequency locking of quasi-periodic solutions A. Seifert, H. Hetzler University of Kassel, Germany	2308
Numerical method for transient analysis of beams with non-linear boundary conditions using a Trefftz-based approach T. Thaller, M. Klanner, K. Ellermann Graz University of Technology, Austria	2320
Controlling spatial and rotational movement of small, acoustically levitated particles by phasing and rotating piezoelectric transducer arrays S. Yosifov, I. Bucher, E. Uzhansky, Y. Zinger Technion, Israel	2335

---

**OMA**

## Session Operational modal analysis

- On the use of fiber optic sensors and operational modal analysis for structural health monitoring in aerospace structures 2346  
 R. G. Sbarra, E. Del Priore, G. Coppotelli, L. Lampani, M. Pasquali  
 La Sapienza University of Rome, Italy
- Modal characterization of a helicopter stabilizer from flight test campaign with externally mounted accessory 2359  
 D. Ricardo Ambrosio <sup>(1)</sup>, E. Alexandre Camargo <sup>(2)</sup>, V. Candido de Sousa <sup>(3)</sup>, D. Fernando Castillo Zúñiga <sup>(3)</sup>, M. Sartorato <sup>(3)</sup>, N. Costa <sup>(4)</sup>, É. Luiz Oliveira <sup>(3)</sup>  
 (1) Aeronautical Institute of Technology, Brazil  
 (2) Institute of Aeronautics and Space, Brazil  
 (3) São Paulo State University, Brazil  
 (4) Hottinger Brüel & Kjær A/S, Denmark
- Effect of rotational speed on the modal parameters of a helicopter blade based on operational modal analysis approach 2366  
 E. Alexandre Camargo <sup>(1)</sup>, D. Ricardo Ambrosio <sup>(2)</sup>, V. Candido de Sousa <sup>(3)</sup>, D. Fernando Castillo Zúñiga <sup>(3)</sup>, M. Sartorato <sup>(3)</sup>, N. Costa <sup>(4)</sup>, É. Luiz Oliveira <sup>(3)</sup>  
 (1) Institute of Aeronautics and Space, Brazil  
 (2) Aeronautics Institute of Technology, Brazil  
 (3) São Paulo State University, Brazil  
 (4) Hottinger Brüel & Kjær A/S, Denmark
- Experimental and numerical investigation of the influence of the ductile-to-brittle transition of steel on the modal characteristics of a Vierendeel truss bridge 2377  
 D. Anastasopoulos, E. P. B. Reynders  
 KU Leuven, Belgium
- 

**OMCV**

## Session Optical Methods Computer vision for Vibration Engineering

- Thermoelasticity-based strain experimental modal analysis 2392  
 K. Zaletelj, J. Šonc, J. Slavič, M. Boltežar  
 University of Ljubljana, Slovenia
- A novel phase motion estimation method for structural vibration measurement using two-dimensional hilbert transform 2399  
 K. Xie, L.-L. Cheng  
 University of Groningen, Netherlands
- Local digital image correlation algorithms: spatial domain versus frequency domain approach 2411  
 P. Neri <sup>(1)</sup>, A. Paoli <sup>(1)</sup>, S. Occhipinti <sup>(2)</sup>, C. Furrone <sup>(2)</sup>, D. Botto <sup>(2)</sup>  
 (1) University of Pisa, Italy  
 (2) Politecnico di Torino, Italy

---

Assessment of three-dimensional displacements via a novel natural-pattern tracking algorithm	2421
F. Bottalico, A. Sabato University of Massachusetts Lowell, United States of America	
Reconstruction of cylinder flexural vibration and sound radiation fields from multi-view single-camera measurements	2430
S. Baldini <sup>(1)</sup> , G. Guernieri <sup>(1)</sup> , D. Gorjup <sup>(2)</sup> , P. Gardonio <sup>(1)</sup> , J. Slavič <sup>(2)</sup> , R. Rinaldo <sup>(1)</sup> (1) University of Udine, Italy (2) University of Ljubljana, Slovenia	
Exploiting vision-based motion measurements for the experimental model identification of flexible multibody mechanisms	2442
T. Willems <sup>(1,2)</sup> , K. Zaletelj <sup>(3)</sup> , S. Vanpaemel <sup>(1,2)</sup> , J. Slavič <sup>(3)</sup> , F. Naets <sup>(1,2)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium (3) University of Ljubljana, Slovenia	
Reconstruction of the sound radiation field from plate DIC vibration measurements	2456
D. Mastrodicasa <sup>(1,2)</sup> , A. Morrone <sup>(1,3)</sup> , E. Di Lorenzo <sup>(1)</sup> , C. Colangeli <sup>(1)</sup> , F. Cosco <sup>(1,3)</sup> , B. Peeters <sup>(1)</sup> (1) Siemens Industry Software NV, Belgium (2) Vrije Universiteit Brussel, Belgium (3) University of Calabria, Italy	
A non-invasive characterization approach based on digital twin developed using vibration-response	2467
S. R. Atashipour, F. Rouhollahi, J. Baqersad Kettering University, United States of America	
Video motion and modal magnification: towards a new paradigm for OMA	2473
F. Cosco <sup>(1,2)</sup> , D. Mastrodicasa <sup>(2)</sup> , D. Mundo <sup>(1)</sup> , E. Di Lorenzo <sup>(2)</sup> (1) University of Calabria, Italy (2) Siemens Digital Industries Software, Belgium	
Vibration measurement with event cameras	2483
S. Baldini, R. Bernardini, A. Fusiello, P. Gardonio, R. Rinaldo Università degli Studi di Udine, Italy	
Analysis of nonlinear vibrations of a blade with dovetail attachment using DIC and the smoothed harmonics analysis	2496
S. Occhipinti <sup>(1)</sup> , A. Cesaretti <sup>(1)</sup> , P. Neri <sup>(2)</sup> , C. M. Firrone <sup>(1)</sup> , D. Botto <sup>(1)</sup> (1) Politecnico di Torino, Italy (2) University of Pisa, Italy	
Enhancing dynamic analysis of mechanical systems using dynamic gaussian splatting and motion magnification	2505
W. Bittner, T. Slimak, H. Jung Technical University of Munich, Germany	
Pixel based experimental modal analysis	2520
I. Tomac <sup>(1,2)</sup> , D. Gorjup <sup>(2)</sup> , J. Slavič <sup>(2)</sup> (1) University of Split, Croatia (2) University of Ljubljana, Slovenia	

---

Examining the dynamic characteristics of a tennis racket through high-speed videos D. Herfert, J. Krause, K. Henning, M. Gollnick Society for the Advancement of Applied Computer Science, Germany	2529
Damage detection in 3D-printed metal alloys by characterization of modal behaviour A. M. Peshave <sup>(1,2)</sup> , L. Wittevrongel <sup>(1)</sup> , F. Pierron <sup>(1,2)</sup> , P. Lava <sup>(1)</sup> (1) MatchID NV, Belgium (2) Ghent University	2537
Application of digital image correlation in operational modal analysis of rotating structures S. Occhipinti <sup>(1,2)</sup> , D. Mastrodicasa <sup>(2,3)</sup> , S. Manzato <sup>(2)</sup> , E. Di Lorenzo <sup>(2)</sup> (1) Politecnico di Torino, Italy (2) Siemens Industry Software NV, Belgium (3) Vrije Universiteit Brussel, Belgium	2544

---

**PER**

Session Periodic structures and metamaterials

Dynamic study of bandgap in hierarchical metastructure T. Gupta, B. Bhattacharya Indian Institute of Technology Kanpur, India	2556
Vibration attenuation with shape memory alloy-embedded resonators K. W. Lopes, L. P. R. de Oliveira University of São Paulo, Brazil	2566
Numerical and experimental investigations of wave propagation in Kelvin Cell-based periodic lattice architectures L. Kleine-Wächter <sup>(1,2)</sup> , R. Rumlper <sup>(2,3)</sup> , H. Mao <sup>(2,3)</sup> , P. Göransson <sup>(2,3)</sup> , G. Müller <sup>(1)</sup> (1) Technical University of Munich, Germany (2) KTH Royal Institute of Technology Stockholm, Sweden (3) The Centre for ECO2 Vehicle Design, Sweden	2579
Sound transmission loss dip compensation using multi-resonant vibroacoustic metamaterial designed for injection moulding K. Chojnacka <sup>(1,2)</sup> , A. Kras <sup>(2)</sup> , T. Kamisiński <sup>(1)</sup> (1) AGH University of Krakow, Poland (2) Silencions Sp. z o.o., Poland	2594
Improving the low-frequency vibration performance of metamaterials with high-static-low-dynamic stiffness local resonators D. R. Santo <sup>(1,2,3)</sup> , E. Deckers <sup>(3,4)</sup> , C. Claeys <sup>(2,3)</sup> , R. F. Boukadia <sup>(2,3)</sup> , L. R. P. de Oliveira <sup>(1)</sup> (1) University of São Paulo, Brazil (2) KU Leuven, Belgium (3) Flanders Make @ KU Leuven, Belgium (4) KU Leuven Campus Diepenbeek, Belgium	2606

---

Modeling and numerical analysis of waveguides in defective phononic crystal lattice structures	2617
W. V. O. Monteiro <sup>(1)</sup> , E. D. Nóbrega <sup>(2)</sup> , J. M. C. dos Santos <sup>(1)</sup>	
(1) University of Campinas, Brazil	
(2) Federal University of Maranhão, Brazil	
A modified generalized Bloch-mode synthesis for the efficient modeling of periodic structures using the wave-based finite element method	2627
V. M. d. S. Santos <sup>(1,2)</sup> , T. d. P. Sales <sup>(1)</sup> , M. Ouisse <sup>(2)</sup>	
(1) Aeronautics Institute of Technology, Brazil	
(2) Université de Franche-Comté, France	
A multi-mode smart metamaterial for NVH control	2642
G. K. Rodrigues, L. P. R. de Oliveira	
University of São Paulo, Brazil	
Locally resonant metamaterial wall targeting tonal noise arising from heat pumps in residential buildings	2652
R. Zeng <sup>(1,2,3)</sup> , E. Deckers <sup>(1,4)</sup> , C. Glorieux <sup>(1)</sup> , D. Urbán <sup>(2,5)</sup> , B. Chmielewski <sup>(3)</sup>	
(1) KU Leuven, Belgium	
(2) STU Bratislava, Slovakia	
(3) KFB Acoustics sp. z o. o., Poland	
(4) Flanders Make @ KU Leuven, Belgium	
(5) Technische Universität Wien, Vienna	
Sound directivity control by tailoring piezoelectric metamaterial vibration modes	2662
C. Sanches Schmidt <sup>(1)</sup> , L. P. R. de Oliveira <sup>(1)</sup> , S. Janssen <sup>(2,3)</sup> , C. Claeys <sup>(2,3)</sup> , E. Deckers <sup>(2,3)</sup> , C. De Marqui Junior <sup>(1)</sup>	
(1) University of Sao Paulo, Brazil	
(2) KU Leuven, Belgium	
(3) Flanders Make @ KU Leuven, Belgium	
Topological wave states in electromechanical metamaterials	2676
B. A. Souto <sup>(1)</sup> , D. Beli <sup>(2)</sup> , C. De Marqui Jr. <sup>(1)</sup>	
(1) University of Sao Paulo, Brazil	
(2) Eindhoven University of Technology, The Netherlands	
Quantifying the impact of variability on locally resonant metamaterial performance through reduced order modeling	2681
R. F. Boukadia <sup>(1,2)</sup> , Y. Pillot <sup>(1,2)</sup> , E. Deckers <sup>(1,2)</sup> , W. Desmet <sup>(1,2)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make @ KU Leuven, Belgium	
Dynamic analysis of metamaterials for industrial applications: numerical predictions and experimental results	2689
A. P. Daga, L. Viale, D. Agabiti, A. Fasana, L. Garibaldi	
Politecnico di Torino, Italy	

Optimization of 3D lattice metastructures based on distorted Kelvin cell for low-frequency vibration suppression	2703
H. Mao <sup>(1)</sup> , H. Zhao <sup>(3)</sup> , J. Larsson <sup>(1)</sup> , B. Yin <sup>(3)</sup> , R. Rumpler <sup>(1,2)</sup> , G. Tibert <sup>(1)</sup> , P. Göransson <sup>(1,2)</sup>	
(1) KTH Royal Institute of Technology, Sweden	
(2) Marcus Wallenberg Laboratory for Sound and Vibration Research, Sweden	
(3) Zhejiang University, China	
Variable cross-section metabeams with resonators for enhanced vibration attenuation capabilities	2714
S. Sahana, A. Singh, B. Bhattacharya	
Indian Institute of Technology Kanpur, India	

---

## RAIL

### Session Railway dynamics and ground vibrations

Some observations on the significance of soil-structure interaction in the transmission of ground-borne vibration into buildings	2726
J. P. Talbot, T. Edirisinghe	
University of Cambridge, United Kingdom	
Railway track matching through curvature correlation	2733
P. Roberto Gardel Kurka, L. Fernandes von Huelsen	
Universidade Estadual de Campinas, Brazil	
Mitigation of environmental ground vibration in layered soils using seismic metasurfaces	2744
Z. Kabirian, D. Carneiro, G. Lombaert, G. Degrande	
KU Leuven, Belgium	
A methodology to manage the complexity of a nonlinear multibody digital twin in railway applications	2756
B. Auzanneau <sup>(1,2)</sup> , E. Sadoulet-Reboul <sup>(1)</sup> , E. Foltête <sup>(1)</sup> , G. Ham-Livet <sup>(2)</sup> , S. Cogan <sup>(1)</sup>	
(1) Université de Franche-Comté, France	
(2) ALSTOM Transport SA, France	
On the influence of speed and track quality on the comfort index treated as a stochastic variable for railway vehicles	2765
D. R. León, E. Palomares, A. L. Morales, A. J. Nieto, J. M. Chicharro, P. Pintado	
Universidad de Castilla-La Mancha, Spain	
Elastic wave propagation characteristics of periodic track structure in urban rail transit	2775
P. Li <sup>(1)</sup> , Z. Zeng <sup>(1)</sup> , M. Ye <sup>(1,2)</sup>	
(1) Central South University, China	
(2) Ghent University, Belgium	

## SD

## Session Structural dynamics: methods and case studies

A numerical model for reconstructing the transport-induced vibration of paintings on a testbed	2784
Y. Gao, P. Ziegler, P. Eberhard University of Stuttgart, Germany	
Rattling detection of electric components	2799
J. A. Erdelyi <sup>(1)</sup> , Z. G. Gazdagh <sup>(1,2)</sup> , A. Bartus <sup>(1)</sup> , B. Fukker <sup>(1)</sup> (1) Robert Bosch Kft, Hungary (2) Széchenyi István University, Hungary	
Geometrical parameterization of a finite element model to account for material variability in classical guitar design	2814
P. Cillo, P. Ziegler, P. Eberhard University of Stuttgart, Germany	
Optimization of the ultrasonic dynamics and kinematics for a micron-scale accurate ultrasonic transducer	2825
D. Shapira, I. Bucher Technion, Israel	
Dynamic fixture development for a structure with two independent attachment points	2840
C. Taylor <sup>(1)</sup> , J. DeClerck <sup>(1)</sup> , J. Blough <sup>(1)</sup> , C. VanKarsen <sup>(1)</sup> , D. Labyak <sup>(1)</sup> , R. Joshua <sup>(2)</sup> (1) Michigan Technological University, United States of America (2) Kansas City National Security Campus, United States of America	
Modal characterization of a PMSM using different experimental techniques	2852
F. Soresini, D. Barri, S. Manzoni, F. M. Ballo, M. Gobbi Politecnico di Milano, Italy	
Vibrations from treadmills	2866
J. E. Torres, A. Buen Brekke Strand Akustikk, Norway	
Identification of natural frequencies of Pelton runners during transient operating conditions	2879
M. Chiarelli <sup>(1)</sup> , R. M. Boes <sup>(2)</sup> , D. F. Vetsch <sup>(2)</sup> , G. Blommaert <sup>(3)</sup> , M. Boden <sup>(4)</sup> , C. Münch-Alligné <sup>(1)</sup> (1) HES-SO Valais-Wallis, Switzerland (2) ETH Zurich, Switzerland (3) HYDRO Exploitation SA, Switzerland (4) Alpiq SA, Switzerland	
Vibration fatigue analysis of laser welds on battery modules	2890
J. Manterola, H. Usabiaga, I. Leciñana, M. Olave IKERLAN Technology Research Centre, Spain	

---

A new design and optimization method of a nano-aerial vehicle with resonant vibrating wings	2902
M. de La Bigne <sup>(1,2)</sup> , E. Cattan <sup>(1)</sup> , S. Ghenna <sup>(1)</sup> , M. Zwingelstein <sup>(1)</sup> , S. Grondel <sup>(1)</sup> , O. Thomas <sup>(2)</sup>	
(1) Univ. Polytechnique Hauts-de-France, France	
(2) HESAM Université, France	
Longitudinal stability analysis of an insect-like flapping wing micro aerial vehicle operating at variable forward flight speed	2912
J. Vanpoucke, T. Roelandt, D. Vandepitte	
KU Leuven, Belgium	
A novel multimodal piezoelectric vibration energy harvester integrated with a practical read-out circuit	2927
M. Askari <sup>(1)</sup> , M. Ghandchi Tehrani <sup>(1)</sup> , E. Brusa <sup>(2)</sup> , A. Carrera <sup>(2)</sup> , C. Delprete <sup>(2)</sup>	
(1) University of Groningen, The Netherlands	
(2) Politecnico di Torino, Italy	
Experimental method to predict critical buckling pressure of thin wall vessel using acoustic actuation and sensing	2942
Y. Poleg, I. Bucher, A. Minikes	
Technion, Israel	
Flywheel inertial vibration absorber	2953
A. Kras <sup>(1)</sup> , P. Gardonio <sup>(2)</sup>	
(1) Silencions, Poland	
(2) Università degli Studi di Udine, Italy	
Tribo-dynamics of balanced vane pumps for automotive applications and experimental validation	2966
C. Natali, M. Battarra, G. Dalpiaz, E. Mucchi	
University of Ferrara, Italy	
Testing and modelling of nonlinear dynamic behavior of linear guideways	2979
Y.-C. Lo, Y.-J. Chan	
National Chung Hsing University, Taiwan	
Knowledge graphs for digital twins of structural dynamic systems	2989
X. Shen <sup>(1)</sup> , P. Devaraja <sup>(2)</sup> , D. Wagg <sup>(1,2)</sup> , M. Bonney <sup>(3)</sup>	
(1) The Alan Turing Institute, UK	
(2) University of Sheffield, UK	
(3) University of Swansea, UK	
Space rider: thermal protection system configuration and body flap development test	3004
B. Tiseo, G. C. Rufolo, R. Fauci, A. Concilio, F. Di Caprio, R. Scigliano, F. M. Pisano, R. Gardi, M. De Stefano Fumo, M. Fragiaco, V. Quaranta, G. Bruno	
CIRA Centro Italiano Ricerche Aerospaziali, Italy	
Analysis of the experimental properties of CubeSat-class satellites for the simplification of the launch clearance process	3017
M. Boscia, R. G. Sbarra, G. Coppotelli, F. Piergentili	
Sapienza University of Rome, Italy	

---

Mode veering in dynamic systems via inertial coupling S. Adhikari, A. Jacques University of Glasgow, United Kingdom	3032
Experimental study of low frequency chatter vibrations in robotic milling A. Bartfai <sup>(1)</sup> , I. Laka <sup>(2)</sup> , J. Munoa <sup>(2)</sup> , Z. Dombovari <sup>(1)</sup> (1) Budapest University of Technology and Economics, Hungary (2) IDEKO, Spain	3047
Condition monitoring of a broaching machine through machine learning classification of a limited dataset vibration signals S. Rosa, A. Martini, A. Rivola, M. Troncossi University of Bologna, Italy	3055
Estimation of gear mesh stiffness in spur gears through finite element model and analytical approach A. El Amlil <sup>(1)</sup> , B. El Yousfi <sup>(2)</sup> , A. Soualhi <sup>(1)</sup> , F. Guillet <sup>(1)</sup> (1) Université Jean Monnet Saint-Etienne, France (2) École Militaire Polytechnique, Algérie	3069
Sound quality analysis of door and drawer openings on washing machines M. Rossini <sup>(1,2)</sup> , M. De Marco <sup>(2)</sup> , N. Prodi <sup>(1)</sup> , A. Acri <sup>(2)</sup> (1) University of Ferrara, Italy (2) Haier Europe, Italy	3082

---

## SHM

### Session Structural health monitoring (Structures)

Using transfer learning in physics informed neural networks for online structural health monitoring C. Martinelli <sup>(1,2)</sup> , A. Soderqvist <sup>(1)</sup> , A. Cammarano <sup>(1,3)</sup> (1) University of Glasgow, United Kingdom (2) University of Strathclyde, United Kingdom (3) University of Southampton, United Kingdom	3094
Knowledge sharing for improving damage identification across a population of heterogeneous laboratory-scale aircraft models G. Delo <sup>(1)</sup> , C. Surace <sup>(1)</sup> , K. Worden <sup>(2)</sup> (1) Politecnico di Torino, Italy (2) University of Sheffield, United Kingdom	3109
On the topology and geometry of population-based SHM K. Worden, T. A. Dardeno, A. J. Hughes University of Sheffield, United Kingdom	3120
Early experiences in monitoring systems for offshore platforms: towards an integrated approach for asset integrity and model updating J. Salvi, L. Rinaldi Solgeo S.r.l., Italy	3138

---

The influence of pre-existing corrosion damage on vibration-based monitoring during mechanical load-testing of reinforced concrete beams M. van de Velde, E. Vandecruys, E. Verstrynge, E. Reynders, G. Lombaert KU Leuven, Belgium	3147
Comparative analysis of time-stretching and MWCS techniques for compensation of environmental effects in structural health monitoring of concrete infrastructure J. Kumar Sharma, A. Deraemaeker Université Libre de Bruxelles (ULB), Belgium	3161
Issues in Damage Detection Using Autocovariance Functions J. Kullaa Metropolia University of Applied Sciences, Finland	3174
Robust full-field modal testing method for structural health monitoring of aerostructures under random noise M. Y. Belur <sup>(1)</sup> , A. Kefal <sup>(1)</sup> , S. D. Fassois <sup>(2)</sup> , P. Spiliotopoulos <sup>(2)</sup> (1) Sabanci University, Turkiye (2) University of Patras, Greece	3185
Random vibration based robust structural health monitoring for a composite wing-shaped structure under temperature uncertainty: an exploratory study G. Kakolyris <sup>(1)</sup> , S. D. Fassois <sup>(1)</sup> , A. Kefal <sup>(2)</sup> , M. Y. Belur <sup>(2)</sup> (1) University of Patras, Greece (2) Sabanci University, Turkey	3197
Vibration data based robust damage detection under unobservable operating conditions via the functional model based method P. E. Spiliotopoulos, S. D. Fassois, J. S. Sakellariou University of Patras, Greece	3211
Vibration-based structural health monitoring of the mooring lines in a floating offshore wind turbine under varying environmental conditions: NN vs STS based methods X. Konstantinou <sup>(1)</sup> , K. Kritikakos <sup>(1)</sup> , C. F. Lee <sup>(2)</sup> , C. S. Sakaris <sup>(3)</sup> , J. S. Sakellariou <sup>(1)</sup> , R. Schlanbusch <sup>(3)</sup> , M. C. Ong <sup>(2)</sup> (1) University of Patras, Greece (2) University of Stavanger, Norway (3) Norwegian Research Centre, Norway	3224
Defect detection in additively manufactured parts using frequency domain-based correlation criteria G. Deonarain, J. Blough, D. Labyak Michigan Technological University, United States of America	3239
Sensor fault detection and identification for robust SHM in a population of composite aerostructures under varying excitation and temperature I. E. Saramantas <sup>(1)</sup> , J. S. Sakellariou <sup>(1)</sup> , S. D. Fassois <sup>(1)</sup> , I. A. Iliopoulos <sup>(1)</sup> , D. N. Serpanos <sup>(2,3)</sup> (1) University of Patras, Greece (2) CTI Diophantus, Greece (3) Athena Research Center, Greece	3254

Best features extraction for ML-based structural health monitoring L. Severa, S. Milana, N. Roveri, A. Culla, A. Carcaterra Sapienza University of Rome, Italy	3268
Acoustic source separation of transient events from background noise C. A. Paprocki <sup>(1)</sup> , A. Barnard <sup>(1)</sup> , T. Dare <sup>(1)</sup> , K. Cody <sup>(2)</sup> , P. Newman <sup>(3)</sup> (1) Penn State, Acoustics, United States of America (2) Naval Nuclear Laboratory, United States of America (3) Penn State, Recreation, Parks, and Tourism Management, United States of America	3283
Cook's distance-based regression to enhance clustering of metal additive manufactured components through a resonance testing system D. Candelaresi <sup>(1,2)</sup> , G. Kosova <sup>(1)</sup> , A. Annessi <sup>(2)</sup> , E. Di Lorenzo <sup>(1)</sup> , M. Martarelli <sup>(2)</sup> , P. Castellini <sup>(2)</sup> (1) Siemens Industry Software NV, Belgium (2) Università Politecnica delle Marche, Italy	3297
When does a bridge become an aeroplane? T. A. Dardeno <sup>(1)</sup> , L. A. Bull <sup>(2,3)</sup> , N. Dervilis <sup>(1)</sup> , K. Worden <sup>(1)</sup> (1) University of Sheffield, UK (2) University of Cambridge, UK (3) University of Glasgow, Scotland	3312
Effect of testing and analysis parameters on efficiency and sensitivity of FDAC for defect detection G. Deonarain, J. Blough, D. Labyak Michigan Technological University, United States of America	3321
Self-training anomaly detection in vibrational and acoustic data J. A. Erdélyi, M. Farkas, B. Fucker Robert Bosch Kft., Hungary	3335
Towards an active-learning approach to resource allocation for population-based damage prognosis G. Tsialiamanis, K. Worden, N. Dervilis, A. J. Hughes University of Sheffield, United Kingdom	3343
Using readily available SHM data to gain insights into the dynamic behaviour of bridges C. Kent, C. O'Higgins, D. Hester, S. Taylor, R. Woods Queen's University Belfast, United Kingdom	3354
On the use of synthetic data for SHM: a short investigation on a laboratory structure E. Papatheou <sup>(1)</sup> , G. Manson <sup>(2)</sup> , R. S. Battu <sup>(1)</sup> , K. Worden <sup>(2)</sup> , G. Tsialiamanis <sup>(2)</sup> (1) University of Exeter, United Kingdom (2) University of Sheffield, United Kingdom	3369
A hybrid modeling strategy for training data generation in machine learning-based structural health monitoring T. Vrtač, D. Ocepek, M. Boltežar, G. Čepon University of Ljubljana, Slovenia	3377

---

**SC**

## Session Substructuring and Coupling

- On the dynamic behavior of bladed disks using wave finite element strategies and model reduction techniques 3392  
J.-M. Mencik <sup>(1,2,3)</sup>, P. Nikiema <sup>(1,2,3)</sup>, M. Mbaye <sup>(4)</sup>  
(1) INSA Centre Val de Loire, France  
(2) Université d'Orléans, France  
(3) Université de Tours, France  
(4) Safran Tech, France
- A framework for correcting measurement position and directions to improve experimental frequency-based substructuring and hybrid models 3406  
M. Brøns <sup>(1,2)</sup>, F. Trainotti <sup>(2)</sup>  
(1) Technical University of Denmark, Denmark  
(2) Technical University of Munich, Germany
- Assessment of a substructuring model and dynamic characterization of anti-vibrating mounts 3419  
S. Tincani <sup>(1,2)</sup>, S. Delvecchio <sup>(3)</sup>, M. Barbieri <sup>(4)</sup>  
(1) Robert Bosch GmbH, Germany  
(2) KU Leuven, Belgium  
(3) Ferrari S.p.a, Italy  
(4) University of Modena and Reggio Emilia, Italy
- Improving experimental impulse-based substructuring through interface weakening 3429  
O. M. Zobel, F. Trainotti, D. J. Rixen  
Technical University of Munich, Germany
- Co-simulation correction in multibody systems through eigenstructure assignment 3444  
D. Richiedei <sup>(1)</sup>, I. Tamellin <sup>(1)</sup>, F. González <sup>(2)</sup>  
(1) University of Padova, Italy  
(2) University of A Coruña, Spain
- Comparison of the numerical accuracy of CMS and FBS techniques in FEM calculations 3456  
M. Herbst  
BETA CAE Systems SA, Greece
- On the multi-domain transmissibility evaluation of dynamic structures with reduced-order models through frequency based substructuring 3471  
A. Zucchini <sup>(1,2)</sup>, A. Hülsmann <sup>(1)</sup>, F. Naets <sup>(2,3)</sup>  
(1) BMW Group, Germany  
(2) KU Leuven, Belgium  
(3) Flanders Make @ KU Leuven, Belgium
- System identification of nonlinear attachments for the dynamic substructuring round robin structure 3486  
B. Moldenhauer <sup>(1)</sup>, D. Roettgen <sup>(1)</sup>, A. Linderholt <sup>(2)</sup>  
(1) Sandia National Laboratories, United States of America  
(2) Linnaeus University, Sweden

Evaluation of the configuration-dependent dynamics of a cartesian 3D printer using substructuring techniques	3497
M. G. Antonelli <sup>(1)</sup> , J. Brunetti <sup>(1)</sup> , W. D'Ambrogio <sup>(1)</sup> , A. Fregolent <sup>(2)</sup> , M. Ialonardi <sup>(2)</sup>	
(1) Università degli Studi dell'Aquila, Italy	
(2) Università degli Studi di Roma La Sapienza, Italy	
Dynamic substructuring based on the complex Udwadia-Kalaba formalism	3510
F. Fabre <sup>(1)</sup> , J.-L. Le Carrou <sup>(1)</sup> , B. Chomette <sup>(2)</sup>	
(1) Sorbonne Université, France	
(2) Ecole Centrale de Lyon, France	
A comparative analysis of frequency- and impulse-based substructuring for experimental shock response predictions	3519
F. Trainotti, O. M. Zobel, D. J. Rixen	
Technical University of Munich, Germany	
A combined VPT and SVT approach for decoupling in the presence of inaccessible and deformable interfaces	3530
M. Di Manno <sup>(1)</sup> , F. Trainotti <sup>(2)</sup> , M. Ialonardi <sup>(1)</sup> , D. J. Rixen <sup>(2)</sup> , A. Fregolent <sup>(1)</sup>	
(1) Università degli studi di Roma La Sapienza, Italy	
(2) Technical University Munich, Germany	
Modal sub-structuring application to the round robin frame structure	3545
N. Pandiya	
Robert Bosch GmbH, Germany	
<hr/>	
<b>TPA</b>	
Session Transfer path analysis	
Experimental modal analysis based TPA method of wiper system linkage vibration amplification	3557
T. F. Varga <sup>(1)</sup> , Z. G. Gazdagh <sup>(1,2)</sup> , L. L. Szabo <sup>(1)</sup> , M. Bubreg <sup>(1)</sup> , B. Fukker <sup>(1)</sup>	
(1) Robert Bosch Kft, Hungary	
(2) Széchenyi István University, Hungary	
Exploring and applying sparse regression in admittance-based TPA methods	3572
D. Ocepek <sup>(1)</sup> , F. Trainotti <sup>(2)</sup> , J. Korbar <sup>(1)</sup> , D. J. Rixen <sup>(2)</sup> , M. Boltežar <sup>(1)</sup> , G. Čepon <sup>(1)</sup>	
(1) University of Ljubljana, Slovenia	
(2) Technical University of Munich, Germany	
Engineering analysis cum assessment of noise and vibration of operator-tractor-field system using operational transfer path analysis	3587
S. Rajan, S. Palanivelu	
Vellore Institute of Technology, India	
Real-time virtual prototype assembly: evaluation of a FIR filter based and a state space model based approach	3602
B. Forrier, F. Bianciardi, M. Elkafafy, K. Janssens	
Siemens Industry Software NV, Belgium	

Importance of data quality: an experimental study of passive-side noise in cTPA measurements	3613
--	------

B. Gergacz <sup>(1,2)</sup>, C. L. Balogh <sup>(1,2)</sup>, T. A. Kimpian <sup>(1,2)</sup>

(1) thyssenkrupp Components Technology Hungary Kft., Hungary

(2) Budapesti Műszaki és Gazdaságtudományi Egyetem, Hungary

---

## TVD

### Session Tuned Vibration Absorbers and Dampers

The virtual tuned mass damper for adaptive vibration absorption on a flexible joint robotic arm	3628
---	------

D. Richiedei, I. Tamellin, A. Trevisani

University of Padova, Italy

Active control of a tuned vibration absorber for use in metamaterial applications	3637
---	------

B. Austin, J. Cheer

University of Southampton, United Kingdom

Experimental investigation of a Tuned Mass Inerter System (TMIS)	3647
--	------

R. Zhang <sup>(1,2)</sup>, J. Xu <sup>(1,2)</sup>, Y. Xia <sup>(3)</sup>

(1) Tongji University, State Key Laboratory for Disaster Reduction in Civil Engineering, China

(2) Tongji University, Department of Disaster Mitigation for Structures, China

(3) Swansea University, United Kingdom

On improving the identification of lumped parameter systems with symmetric mass, damping and stiffness matrices	3654
---	------

N. Feng <sup>(1)</sup>, E. J. Hahn <sup>(2)</sup>, M. Yu <sup>(3)</sup>

(1) Shandong University, China

(2) The University of New South Wales, Australia

(3) NSW Department of Education, Australia

Vacuum plant for structured fabric TVA	3665
--	------

L. Ortis <sup>(1)</sup>, P. Gardonio <sup>(1)</sup>, E. Rustighi <sup>(2)</sup>, C. Malacarne <sup>(3)</sup>, M. Perini <sup>(3)</sup>

(1) DPIA-University of Udine, Italy

(2) DIE-University of Trento, Italy

(3) ProM Facility – Trentino Sviluppo S.p.A., Italy

---

## NVH

### Session Vehicle noise and vibration

Comparison of different electromagnetic forces calculation methods for the analysis of NVH behaviour of electric motors	3679
---	------

D. Barri, F. Soresini, M. Gobbi, A. Di Gerlando, F. M. Ballo, G. Mastinu

Politecnico di Milano, Italy

Full vehicle NVH end-of-line testing and data-driven fault detection of a high-performance hybrid vehicle front e-axle E. Giovannardi <sup>(1)</sup> , S. Delvecchio <sup>(1)</sup> , N. Cavina <sup>(2)</sup> , C. Colangeli <sup>(3)</sup> , B. Cornelis <sup>(3)</sup> , K. Janssens <sup>(3)</sup> (1) Ferrari S.p.A., Italy (2) University of Bologna, Italy (3) Siemens Industry Software NV, Belgium	3694
Dynamic modeling for enhanced acoustic comfort in agricultural machinery: NVH digital twin for tractor pump drive F. Pizzolante <sup>(2)</sup> , A. Artiano <sup>(1,2)</sup> , S. Di Marcoberardino <sup>(2)</sup> , S. Meleti <sup>(2)</sup> , M. Tarabra <sup>(2)</sup> , M. Battarra <sup>(1)</sup> , E. Mucchi <sup>(1)</sup> (1) University of Ferrara, Italy (2) CNH Industrial Italia SpA, Italy	3709
Automated comparison of product sounds – a digital twin approach to jury testing M. Farkas <sup>(1)</sup> , J. A. Erdelyi <sup>(1)</sup> , M. L. Ha <sup>(2)</sup> (1) Robert Bosch Kft, Hungary (2) Robert Bosch GmbH., Germany	3721
Identification of the electromechanical model of a pneumatic positioner for the dynamic actuation of an oscillating platform M. G. Antonelli <sup>(1)</sup> , J. Brunetti <sup>(1)</sup> , W. D'Ambrogio <sup>(1)</sup> , A. Fregolent <sup>(2)</sup> , F. Marafini <sup>(2)</sup> (1) Univerità degli Studi dell'Aquila, Italy (2) Università degli Studi di Roma La Sapienza, Italy	3731
Improved vibration isolation of 1D chiral phononic crystals with viscoelastic inserts L. Mardini <sup>(1,2)</sup> , E. Deckers <sup>(1,3)</sup> , C. Claeys <sup>(1,3)</sup> , B. Van Damme <sup>(2)</sup> (1) KU Leuven, Belgium (2) Empa, Laboratory for Acoustics/Noise Control, Switzerland (3) Flanders Make @ KU Leuven, Belgium	3742
Real-time capable models for fast NVH and sound quality optimization of electric vehicles N. Salamone <sup>(1,2)</sup> , F. Bianciardi <sup>(1)</sup> , C. Colangeli <sup>(1)</sup> , K. Janssens <sup>(1)</sup> , S. Van Ophem <sup>(2,3)</sup> , W. Desmet <sup>(2,3)</sup> (1) Siemens Digital Industries Software NV, Belgium (2) KU Leuven, Belgium (3) Flanders Make, Belgium	3752
Applications of phase-based motion magnification in vibration analysis of steering systems S. Gungl, K. Horváth, T. A. Kimpián thyssenkrupp Components Technology Hungary Ltd., Hungary	3763
Evaluation of machine learning techniques for the NVH design of electric vehicle battery A. Hense <sup>(1,3)</sup> , F. Chauvicourt <sup>(1)</sup> , M. Brughmans <sup>(1)</sup> , S. van Ophem <sup>(2,4)</sup> , E. Deckers <sup>(3,4)</sup> (1) Siemens Digital Industries Software, Belgium (2) KU Leuven, Belgium (3) KU Leuven, Campus Diepenbeek, Belgium (4) Flanders Make @ KU Leuven, Belgium	3770

---

Control of transfer function distortion during RPM-sweep testing of e-drive systems Z. G. Gazdag <sup>(1,2)</sup> , D. Acs <sup>(1)</sup> , B. Vehovszky <sup>(2)</sup> , B. Fukker <sup>(1)</sup> (1) Robert Bosch Kft, Hungary (2) Széchenyi István University, Hungary	3779
Model-based noise and vibration analysis of electric vehicle E-motor and gearbox H. Wang <sup>(1,2)</sup> , L. Van Belle <sup>(1,2)</sup> , F. Naets <sup>(1,2)</sup> (1) KU Leuven, Belgium (2) Flanders Make @ KU Leuven, Belgium	3788
<hr/>	
VAM	
Session Vibro-acoustic modelling and prediction	
Theoretical prediction of belt properties for tyre-vibration modelling W. R. Graham University of Cambridge, United Kingdom	3802
An industrial benchmark study of automated modal analysis using density-based clustering techniques A. Tavares <sup>(1,2)</sup> , E. Di Lorenzo <sup>(1)</sup> , B. Cornelis <sup>(1)</sup> , S. Manzato <sup>(1)</sup> , B. Peeters <sup>(1)</sup> , W. Desmet <sup>(2,3)</sup> , K. Gryllias <sup>(2,3)</sup> (1) Siemens Industry Software NV, Belgium (2) KU Leuven, Belgium (3) Flanders Make @ KU Leuven, Belgium	3814
An alternative method for finite dimension models of flexible structures via Padé approximation S. Levin <sup>(1)</sup> , Y. Halevi <sup>(1,2)</sup> (1) Technion, Israel (2) Shenkar College, Israel	3826
The effects of model reduction on the shock response spectra of multi-modal structures K. Dubber, T. Waters, N. Ferguson University of Southampton, United Kingdom	3839
Parametric model for emulating absorbing infinite plane in pass-by noise simulations L. Zullo <sup>(1)</sup> , Y. Li <sup>(2)</sup> , H. Beriot <sup>(2)</sup> , L. Berzi <sup>(1)</sup> , N. Baldanzini <sup>(1)</sup> (1) University of Florence, Italy (2) Siemens Digital Industries Software, Belgium	3853
Data-based knowledge transfer to improve the accuracy of physical models in digital twins A. Oyarzabal <sup>(1)</sup> , N. Gil-Negrete <sup>(1)</sup> , A. Alonso <sup>(2)</sup> (1) University of Navarra, Spain (2) CAF I+D, Spain	3868
A wave based method for the modeling of two canyons exposed to an oblique incident wave front M. Lainer, G. Müller Technical University of Munich, Germany	3883

---

A wave-based approach to predict the vibration transmission across junctions with elastic interlayers	3896
S. Moons <sup>(1,2)</sup> , R. Lanoye <sup>(2)</sup> , E. Reynders <sup>(1)</sup>	
(1) KU Leuven, Belgium	
(2) CDM Stravitec, Belgium	
A modified Bayliss-Turkel absorbing boundary condition for non-spherical truncated boundaries of acoustic problems and fast frequency sweeps	3909
P. Mariotti, R. Rimpler, H. Mao	
KTH - Royal Institute of Technology, Sweden	
Enhancing digital twin development through advanced vibroacoustic modeling techniques	3923
D. Bizzarri <sup>(1,2)</sup> , S. van Ophem <sup>(2,3)</sup> , H. Beriot <sup>(1)</sup> , O. Atak <sup>(4)</sup>	
(1) Siemens Industry Software NV, Belgium	
(2) KU Leuven, Belgium	
(3) Flanders Make@KU Leuven, Belgium	
(4) Siemens Digital Industries Software, United Kingdom	
Experimental validation technique for near-2D structures towards the sound transmission loss	3935
V. Cool <sup>(1,2)</sup> , C. Claeys <sup>(1,2)</sup> , H. Denayer <sup>(1,2)</sup> , F. Naets <sup>(1,2)</sup> , E. Deckers <sup>(1,3)</sup>	
(1) KU Leuven, Belgium	
(2) Flanders Make @ KU Leuven, Belgium	
(3) KU Leuven Campus Diepenbeek, Belgium	
Dynamic response of large finite and non-symmetrical two-dimensional periodic structures	3944
D. Duhamel	
Ecole des Ponts ParisTech, France	
A multi-scale homogenization-based approach for dynamic simulation of lattice metamaterials	3958
L. Cibrario <sup>(1)</sup> , C. Gastaldi <sup>(1)</sup> , I. F. Cozza <sup>(2)</sup> , G. Credo <sup>(2)</sup> , M. Saracino <sup>(2)</sup> , C. Delprete <sup>(1)</sup> , F. Scarpa <sup>(3)</sup>	
(1) Politecnico di Torino, Italy	
(2) Dumarey Automotive Italia S.p.A, Italy	
(3) University of Bristol, United Kingdom	
Frequency dependency of acoustic black hole effect in cylindrical shells	3973
K. Hansen, S. V. Sorokin	
Aalborg University, Denmark	
Optimisation of a modified acoustic black hole profile for the reduction of dynamic stress	3988
A. Keys, J. Cheer	
University of Southampton, United Kingdom	
Convergence and comprehensive error analysis of higher-order FE formulations in structural dynamics	3998
A. Karpik, F. Cosco, D. Mundo	
University of Calabria, Italy	

Baseline sensitivity analysis for vibration reduction in mid-frequency range T. Yoshimura, J. Hong Tokyo Metropolitan University, Japan	4012
A superconvergent convolution quadrature method for time-dependent dynamical energy analysis D. J. Chappell Nottingham Trent University, United Kingdom	4024
Methods and applications of computational fluid-structure interaction for nvh problems - a review D. Fabbri, F. Bruzzone, C. Rosso, R. Arina Politecnico di Torino, Italy	4030
Dynamic topology optimization of arbitrarily-shaped 3D structures using a newly developed numerical framework in ABAQUS environment J. Jiang, Y. Xiong University of Southampton, United Kingdom	4045

---

## WIND

### Session Wind turbine dynamics

Application of virtual sensing to enhance fatigue testing of a 70+ meters wind turbine blade D. Tcherniak <sup>(1)</sup> , S. K. Nielsen <sup>(2)</sup> , S. C. van Beveren <sup>(3)</sup> , P. Berring <sup>(4)</sup> , S. Semenov <sup>(4)</sup> , K. Branner <sup>(4)</sup> (1) Hottinger Bruel and Kjaer, Denmark (2) Blaest Blade Test Centre, Denmark (3) LM Wind Power, The Netherlands (4) Technical University of Denmark, Denmark	4056
Frequency domain operational modal analysis methods for fatigue damage progression in laboratory tests of wind turbine blade K. Wrzask <sup>(1)</sup> , A. Tavares <sup>(2)</sup> , E. Di Lorenzo <sup>(2)</sup> , K. Branner <sup>(3)</sup> , M. Łuczak <sup>(1)</sup> (1) Gdańsk University of Technology, Poland (2) Siemens Industry Software NV, Belgium (3) Technical University of Denmark, Denmark	4070
Comparison of modal behaviour in wind turbines based on drivetrain measurements J. Gebel <sup>(1,2)</sup> , P.-J. Daems <sup>(2)</sup> , J. J. Matthys <sup>(2)</sup> , J. Sterckx <sup>(2)</sup> , K. Vratsinis <sup>(2)</sup> , K. Kestel <sup>(2)</sup> , A. R. Nejad <sup>(1)</sup> , J. Helsen <sup>(2)</sup> (1) Norwegian University of Science and Technology (NTNU), Norway (2) Vrije Universiteit Brussel (VUB), Belgium	4081
Wind turbine pitch misalignment detection through tower vibration signal processing F. Castellani <sup>(1)</sup> , F. Belcastro <sup>(2)</sup> (1) University of Perugia, Italy (2) FERA srl, Italy	4092

---

Tonality spread of wind turbines due to production and measurement tolerances P. Becht <sup>(2)</sup> , B. De Smet <sup>(1)</sup> , S. Schmidt <sup>(2)</sup> , B. Blockmans <sup>(1)</sup> (1) KU Leuven, Belgium (2) ZF Wind Power, Belgium	4102
A novel approach for accelerated system-level simulation in wind turbine powertrain testing: analyzing responses to cardan shaft-induced vibrations M. Corno <sup>(1)</sup> , P. Becht <sup>(2)</sup> , B. Blockmans <sup>(1)</sup> , F. Naets <sup>(1)</sup> (1) KU Leuven, Belgium (2) ZF Wind Power Antwerpen NV, Belgium	4113
Digital twin as a service for damage prognosis of offshore wind turbine foundations A. M. D. Jensen <sup>(1)</sup> , A. Schoerghofer-Queiroz <sup>(2)</sup> , M. D. Ulriksen <sup>(1)</sup> , D. Tcherniak <sup>(3)</sup> , L. Damkilde <sup>(1)</sup> , P. Talasila <sup>(1)</sup> , P. G. Larsen <sup>(1)</sup> , G. Abbiati <sup>(1)</sup> (1) Aarhus University, Denmark (2) Vienna Consulting Engineering, Austria (3) Hottinger Brüel & Kjær A/S, Denmark	4127

# USD2024 PAPERS

---

## GREY

### Session Greydient project

- A multifidelity framework for grey-box modelling of automated welding processes 4142  
M. B. Dodt <sup>(1,2)</sup>, L. Bogaerts <sup>(1,2)</sup>, A. Persoons <sup>(1,2)</sup>, M. G. R. Faes <sup>(3)</sup>, D. Moens <sup>(1,2)</sup>  
(1) KU Leuven, Belgium  
(2) Flanders Make @ KU Leuven, Belgium  
(3) TU Dortmund University, Germany
- A transfer learning framework for crashworthiness analysis based on sphere projection and PointNN 4151  
G. Colella <sup>(1,2)</sup>, V. A. Lange <sup>(1)</sup>, F. Duddeck <sup>(2)</sup>  
(1) BMW Group, Germany  
(2) Technical University of Munich, Germany
- Exploring multi-fidelity noisy data: methods and real-world examples 4161  
K. Giannoukou <sup>(1)</sup>, P. Ascia <sup>(2)</sup>, S. Marelli <sup>(1)</sup>, F. Duddeck <sup>(2)</sup>, B. Sudret <sup>(1)</sup>  
(1) ETH Zurich, Switzerland  
(2) Technical University of Munich, Germany
- New insights on reliability analysis for stochastic simulators using surrogate models 4172  
A. V. Pires, M. Moustapha, S. Marelli, B. Sudret  
ETH Zurich, Switzerland
- Physics-informed neural networks to propagate random field properties of composite materials 4182  
D. Bonnet-Eymard <sup>(1)</sup>, A. Persoons <sup>(1)</sup>, P. Gavallas <sup>(2)</sup>, M. GR Faes <sup>(3)</sup>, G. Stefanou <sup>(2)</sup>, D. Moens <sup>(1)</sup>  
(1) KU Leuven, Belgium  
(2) Aristotle University of Thessaloniki, Greece  
(3) TU Dortmund University, Germany
- Enhancing reliability-based design optimization through adaptive Kriging and gradient-free optimization 4193  
A. Faraci, P. Beaurepaire, N. Gayton  
Université Clermont Auvergne, France
- Enhancing development flexibility: a grey-box strategy for adapting to unforeseen adverse conditions 4201  
P. Ascia, F. Duddeck  
Technical University Munich, Germany

---

## USDM3

### Session USD - Methods

- Designing phononic crystals robust against mechanical property variability using statistical data from statistical process control 4216  
 L. H. M. S. Ribeiro <sup>(1)</sup>, C. Claeys <sup>(2,3)</sup>, A. T. Fabro <sup>(4)</sup>, D. Chronopoulos <sup>(2)</sup>, J. R. F. Arruda <sup>(1)</sup>  
 (1) University of Campinas, Brazil  
 (2) KU Leuven, Belgium  
 (3) Flanders Make @ KU Leuven, Belgium  
 (4) University of Brasilia, Brazil
- Model-based comparison of steel-string acoustic guitars with spruce and composite soundboards 4222  
 Y. Giro <sup>(1)</sup>, J.-L. Le Carrou <sup>(1)</sup>, A. Vincenti <sup>(1)</sup>, S. Dartois <sup>(1)</sup>, R. Viala <sup>(1)</sup>, B. Navarret <sup>(2)</sup>  
 (1) Sorbonne Université, France  
 (2) Institut Technologique Européen des Métiers de la Musique, France
- Adaptive Gaussian process regression for robust design optimization using extreme value indicator distribution 4233  
 A. Persoons <sup>(1,2)</sup>, D. Moens <sup>(1,2)</sup>  
 (1) KU Leuven, Belgium  
 (2) Flanders Make @ KU Leuven, Belgium
- Machine learning enabled combined parametric and non-parametric uncertainty in vibro-acoustics 4247  
 A. Cicirello  
 University of Cambridge, United Kingdom
- 

## USDUIQ

### Session USD - Uncertainty Identification and Quantification

- On the impact of model errors on input and state estimation in structural dynamic systems 4262  
 Ø. W. Petersen <sup>(1)</sup>, E.-M. Lourens <sup>(2)</sup>, K. Maes <sup>(3)</sup>  
 (1) NTNU, Norway  
 (2) TU Delft, Netherlands  
 (3) KU Leuven, Belgium
- Fuzzy logic assessment of epistemic uncertainties in pseudo-rigid multibody gear models 4276  
 L. D'Angelo <sup>(1)</sup>, M. Cirelli <sup>(1)</sup>, O. Giannini <sup>(2)</sup>, P. P. Valentini <sup>(1)</sup>  
 (1) University of Rome Tor Vergata, Italy  
 (2) University Niccolò Cusano, Italy
- Experimental results from a model updating study with controlled uncertainty 4291  
 I. Gan <sup>(1)</sup>, S. Fichera <sup>(1)</sup>, S. Bi <sup>(2)</sup>, J. Mottershead <sup>(1)</sup>  
 (1) University of Liverpool, United Kingdom  
 (2) University of Southampton, United Kingdom

Bayesian updating of conditional failure probability using method of moments	4302
P. Li <sup>(1)</sup> , Y. G. Zhao <sup>(2)</sup> , C. Dang <sup>(1)</sup> , M. Broggi <sup>(3)</sup> , M. A. Valdebenito <sup>(1)</sup> , M. G. R. Faes <sup>(1)</sup>	

- (1) TU Dortmund University, Germany  
 (2) Beijing University of Technology, China  
 (3) Institute for Risk and Reliability, Germany

---

## USDA

### Session USD – Applications

Comparison of neural network-based surrogate model and subset simulation for reliability analysis of components submitted to vibrational loads	4314
--	------

- S. Maier <sup>(1,2)</sup>, F. Bachmann <sup>(1)</sup>, R. Feldmann <sup>(2)</sup>  
 (1) BMW Group, Germany  
 (2) Technical University of Darmstadt, Germany

Determination and sensitivity analysis of optimal control parameters of actively steered wheelsets	4326
--	------

- L. Lindbichler, M. Klanner, G. M. Melito, K. Ellermann  
 Graz University Of Technology, Austria

An examination of the Morris analysis in the context of global sensitivity analysis of car crashworthiness with a toy car model	4339
---	------

- D. Brizard <sup>(1,2,3)</sup>, É. Jacquelin <sup>(1,2,3)</sup>  
 (1) Université Lyon, France  
 (2) Université Gustave Eiffel, France  
 (3) Université Claude Bernard Lyon 1, France

Uncertainty quantification for damage detection in 3D printed pure PLA auxetic lattice structure using ultrasonic guided waves and Flipout probabilistic convolutional neural network	4352
---	------

- H. Lu <sup>(1)</sup>, A. Farrokhbadi <sup>(1)</sup>, A. Rauf <sup>(1)</sup>, R. Talemi <sup>(1)</sup>, K. Gryllias <sup>(1,2)</sup>, D. Chronopoulos <sup>(1)</sup>  
 (1) KU Leuven, Belgium  
 (2) Flanders Make @ KU Leuven, Belgium

Deterministic and probabilistic comparison of the discrepancy between the numerical simulation and experimental test considering passive and active vibration isolation	4364
---	------

- M. K. Mohan Kumar, R. Platz  
 Deggendorf Institute of Technology, Germany

Combined primary-secondary structures under imprecise seismic excitation	4378
--	------

- A. Sofi, F. Genovese  
 Università "Mediterranea" di Reggio Calabria, Italy

Thermal virtual sensing for electronic components and systems: exploring the robustness of Kalman filtering	4388
M. Depaola <sup>(1,3,4)</sup> , D. De Gregoriis <sup>(1)</sup> , G. Jouan <sup>(1)</sup> , R. Bornoff <sup>(2)</sup> , O. Atak <sup>(2)</sup> , B. Vandeveldel <sup>(3)</sup> , D. Moens <sup>(4,5)</sup>	
(1) Siemens Industry Software NV, Belgium	
(2) Siemens Digital Industries Software, United Kingdom	
(3) IMEC, Belgium	
(4) KU Leuven, Belgium	
(5) Flanders Make @ KU Leuven, Belgium	
<hr/>	
USDM	
Session USD – Methods	
Reconstruction of random fields concentrated on one-dimensional manifold using irregularly sampled data	4401
G. Perrin, C. Soize	
Université Gustave Eiffel, France	
Random mode evaluation with polynomial chaos expansion	4407
E. Jacquelin <sup>(1)</sup> , S. Adhikari <sup>(2)</sup> , D. Brizard <sup>(1)</sup>	
(1) Université de Lyon, France	
(2) The University of Glasgow, UK	
An efficient reversible-jump MCMC scheme for model term selection in dynamic systems	4422
M. D. Champneys, T. J. Rogers	
University of Sheffield, United Kingdom	
Exploring possibilistic potentials in uncertainty quantification for modal analysis techniques	4432
T. Könecke, M. Hanss	
University of Stuttgart, Germany	
First excursion probability sensitivity by means of Domain Decomposition Method	4443
M. A. Misraji <sup>(1)</sup> , M. A. Valdebenito <sup>(1)</sup> , X.-Y. Zhang <sup>(1,2)</sup> , M. G. R. Faes <sup>(1)</sup>	
(1) TU Dortmund University, Germany	
(2) Beijing University of Technology, China	
Stochastic meshless methods for free vibration analysis of thin beams, and frames with random material density and Young's modulus	4455
M. Aswathy <sup>(1)</sup> , I. R. Praveen Krishna <sup>(2)</sup> , C. O. Arun <sup>(3)</sup>	
(1) Indian Institute of Technology Delhi, India	
(2) Indian Institute of Space Science and Technology Thiruvananthapuram, India	
(3) Indian Institute of Technology Palakkad, India	
Physics-informed Gaussian processes - a guide to what physics where?	4469
D. J. Pitchforth, M. R. Jones, E. J. Cross	
The University of Sheffield, United Kingdom	

---

A reduced-order model for interval analysis in linear dynamical systems N. A. Manque <sup>(1)</sup> , M. A. Valdebenito <sup>(1)</sup> , D. Moens <sup>(2,3)</sup> , M. G. R. Faes <sup>(1)</sup> (1) TU Dortmund University, Germany (2) KU Leuven, Belgium (3) Flanders Make @ KU Leuven	4482
On deriving kernels for linear time-dependent systems M. R. Jones, E. J. Cross The University of Sheffield, United Kingdom	4490
An introduction to optimization under uncertainty - survey K. Shariatmadar, K. Wang, C. R. Hubbard, H. Hallez, D. Moens KU Leuven, Belgium	4503
Analytic derivatives of finite element matrices with respect to geometry A. Bouras, L. Carassale University of Genova, Italy	4519
Cost-informed dimensionality reduction for structural digital twin technologies A. Hughes <sup>(1)</sup> , K. Worden <sup>(1,2)</sup> , N. Dervilis <sup>(1)</sup> , T. Rogers <sup>(1)</sup> (1) The University of Sheffield, United Kingdom (2) The Alan Turing Institute, United Kingdom	4529

# Dynamic modeling for enhanced acoustic comfort in agricultural machinery: NVH digital twin for tractor pump drive

F. Pizzolante <sup>2</sup>, A. Artiano <sup>1,2</sup>, S. Di Marcoberardino <sup>2</sup>, S. Meleti <sup>2</sup>, M. Tarabra <sup>2</sup>, M. Battarra <sup>1</sup>, E. Mucchi <sup>1</sup>

<sup>1</sup> University of Ferrara, Department of Engineering,  
Via G. Saragat, 1 - 44123, Ferrara, FE, Italy

<sup>2</sup> CNH Industrial Italia SpA,  
Viale delle Nazioni, 55 - 41122, Modena, MO, Italy  
e-mail: [francesco.pizzolante@cnh.com](mailto:francesco.pizzolante@cnh.com)

## Abstract

In the domain of agricultural machinery, ensuring user acoustic comfort is a fundamental requirement, given the prolonged hours operators spend on tractors. In this regard, geared transmission systems represent one of the major sources of noise and vibrations as they can produce high frequency whine noise due to their internal excitation. Gear whine noise is mainly caused by transmission errors variation, in fact, this phenomenon is related to gear manufacturing errors, misalignment and time-varying mesh stiffness.

The aim of this paper is to explore the pivotal role of macro and microgeometry in minimizing whine noise emission during gear operation. By emphasizing the substantial impact of transmission error on noise generation, the research activity underscores the relevance of a numerical vibroacoustic methodology, experimentally validated, for the estimation and control of the vibratory level of a geartrain employed on agricultural equipment.

## 1 Introduction

Agricultural tractors represent an intricate system capable of performing multiple operations for different purposes. Throughout its operational life, the various types of sub systems produce noise and vibrations that need to be controlled in order to be acceptable for driver's comfort. Among the critical components in powertrain applications the gearbox system represents a fundamental element, which generates a significant amount of noise during in field operations. Gears are characterized by an internal excitation related to time-varying mesh stiffness and static transmission error, which produce non-linear vibrations. The vibrations generated during the meshing process are transmitted through bearing and shafts to the gearbox case, leading to the emission of the so-called whine noise. The resulting acoustic pressure will depend both on the gear design and gearbox case geometry. Retaining the gearbox case geometry and material, the noise generation mechanism is ruled by gear dynamics. Many authors investigated the role of macro and microgeometry on whine noise occurrence [1, 2, 3, 4, 5]. Different gear macro or microgeometry may be proposed for low-noise design and an evaluation of their dynamic behavior can be achieved by employing a validated virtual model. The initial dynamic models proposed were prevalent linear, as outlined in the review by Ozguven and Houser [6]. However, the nonlinear characteristics of geared systems suddenly emerged in numerous experimental analyses [7, 8, 9]. One of the earliest nonlinear mathematical models was presented by Kahraman and Singh, who initially formulated a single-degree-of-freedom torsional model incorporating backlash clearance [10]. Later, the same authors refined the model with a three-degrees-of-freedom nonlinear model, accounting for time-varying mesh stiffness, backlash, and bearing clearance [11]. The final model, developed by Kahraman and Singh, represents an efficient and dependable tool for predicting the nonlinear dynamics of a gear pair [12].

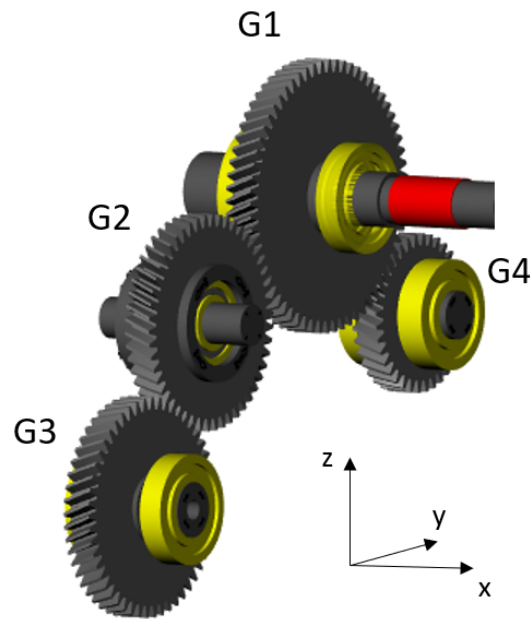


Figure 1: Schematic representation of the pump drive geartrain

This paper aims to face the noise challenges associated with the tractor pump drive as the initial design resulted in considerable noise emissions. Based on this assumption, the authors propose an NVH digital twin of the real gearbox. The developed dynamic model is a combination of two sub-models: a lumped-parameter model (LPM) and a structural finite-element model (FEM). The lumped parameter model was developed by the authors, its reliability has been already proven in [13, 14]. In addition, the model was employed to study analytic formulations related to rattle occurrence [15] and whine noise control [16]. By coupling this two-modeling approaches the virtual strategy is able of capturing interactions among various components of the agricultural transmission system, such as gears, shafts, bearings, and gearbox housing. Firstly, the model was validated with experimental results, ensuring its accuracy in capturing the complex interactions within the transmission system. Subsequently, the validated dynamic model served as a powerful tool to study and evaluate alternative design solutions, considering both macro and microgeometry modifications. This systematic exploration was aimed to identify configurations that could effectively minimize noise emissions while maintaining optimal functionality. The methodology presented in this article, starting from dynamic modeling and leading up in experimental validations, offers a comprehensive and effective approach for addressing noise challenges in agricultural machinery, providing a holistic understanding of the interactions among different elements. The paper is structured as follows: the Section 2 is devoted to experimental characterization; it describes the experimental setup, the metrics employed to quantify the noise and acceleration level and the driveline evaluation. In Section 3, the FEM/LPM model is described, and the numerical-experimental validation is carried out. Finally, in Section 4 the results are presented.

## 2 Experimental test campaign

The following section defines the methodological approach adopted and provides a solid basis for the comprehension of the results. It describes the geartrain under examination, the sensors used, and the software employed for data analysis. In addition, a description of both quantitative and qualitative evaluation criteria for the NVH performance of the component is provided, highlighting the issues encountered during the experimental analysis and subsequently addressed in Section 3. The validation process of an agricultural transmission is an iterative procedure involving several steps and activities aimed to confirm that the final

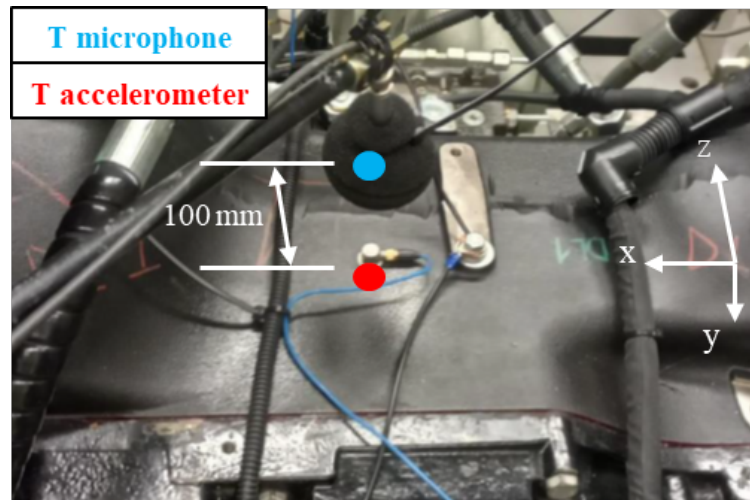


Figure 2: Experimental setup, the picture shows the upper side of the driveline where accelerometer and microphone were installed

product satisfies specified criteria. In this context, the final noise tests are conducted on the complete tractor, to assess the overall quality of the transmission and to ensure compliance with acceptable limits prescribed by regulations. The driveline under examination is a continuously variable transmission. Among all the components within it, an essential role is employed by the pump drive. It consists of a four gears geartrain that connects the internal combustion engine to the hydrostatic unit and one or more hydraulic pumps, providing hydraulic power for a variety of critical functions and enhancing the overall management of system energy and performance. A schematic representation of the geartrain is proposed in figure 1, gears are identified as G1, G2, G3 and G4. G1 is mounted on the input shaft, which is connected to the engine, not shown in the figure. An intermediate shaft supports the idler G2, which transfers power to G3 connected to the hydraulic pumps. G1 also transfers motion to G4, which is connected to the hydrostatic group. The experimental analysis took place inside a non-anechoic test room, where the transmission was connected to an electric motor with the flanged wheels linked to hydraulic brakes. The instrumentation used includes: a Siemens LMS SCADAS acquisition system, a series of triaxial ICP accelerometers and diffuse-field microphones. One accelerometer, positioned on the front housing surface, was considered for the evaluation as it ensures global coverage of system dynamics. The point where the accelerometer was placed will be referred as "T Accelerometer," while the microphone was located approximately 10 centimeters away from the surface and labeled as "T Microphone". The figure 2 illustrates the sensor placement scheme. Several operating conditions were considered in the test plan, however in the following paper, only two test that closely resemble the actual operating conditions of the pump drive will be discussed. One stationary high-speed tests identified as Test 2 and a run-up engine speed test. The Test 2 stationary test was identified as the most critical for the pump drive gear NVH performance, while the run-up engine speed test allows to have a comprehensive view of the system dynamics at different frequencies. To analyze the vibroacoustic phenomenon, both qualitative and quantitative metrics were utilized. When assessing the specific contribution of individual components, such as the pump drive, measured quantities like vibration and sound pressure can be correlated with engine speed by orders extraction in run-up tests. The quantitative metric used is then described as follow: the difference between the overall level and a specific vibration order must remain under a certain threshold. By looking at figure 3 (a), a certain vibration order is represented by the solid blue line while the overall level is depicted by a solid red line. As long as engine rpm are low the order has a considerable delta with respect the overall level. By approaching higher engine speed this difference tends to zero. The "Quantity: Overall - Order" graph in figure 3 (b) shows the same concept, plotting difference between the overall level and the order itself. The second metric is a qualitative sound evaluation metric. It replicates a psychoacoustic metric that describes how the human auditory system's sensitivity can perceive and identify a single tone present in a sound spectrum. The ability to distinguish a tone is not tied to its absolute amplitude but to its relative amplitude compared to the background noise level, figure 3 (b). The latter referred as the order extraction

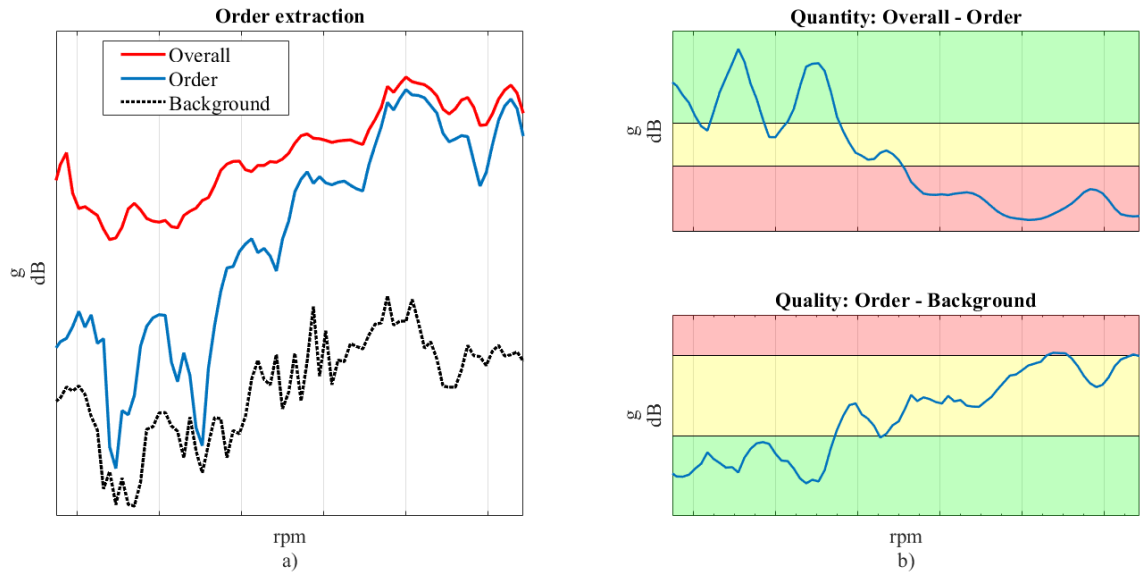


Figure 3: Order extraction compared to the overall and background level (a). Qualitative and quantitative acceptance criteria (b)

next to the source order. In fact the black dashed line, figure 3 (a), shows the background vibration level around a single source order. The quality of perceived sound gets worse as long as the difference between the order and its background level gets higher. The evaluation is performed by measuring the delta between the source order noise with its background level, figure 3 (b).

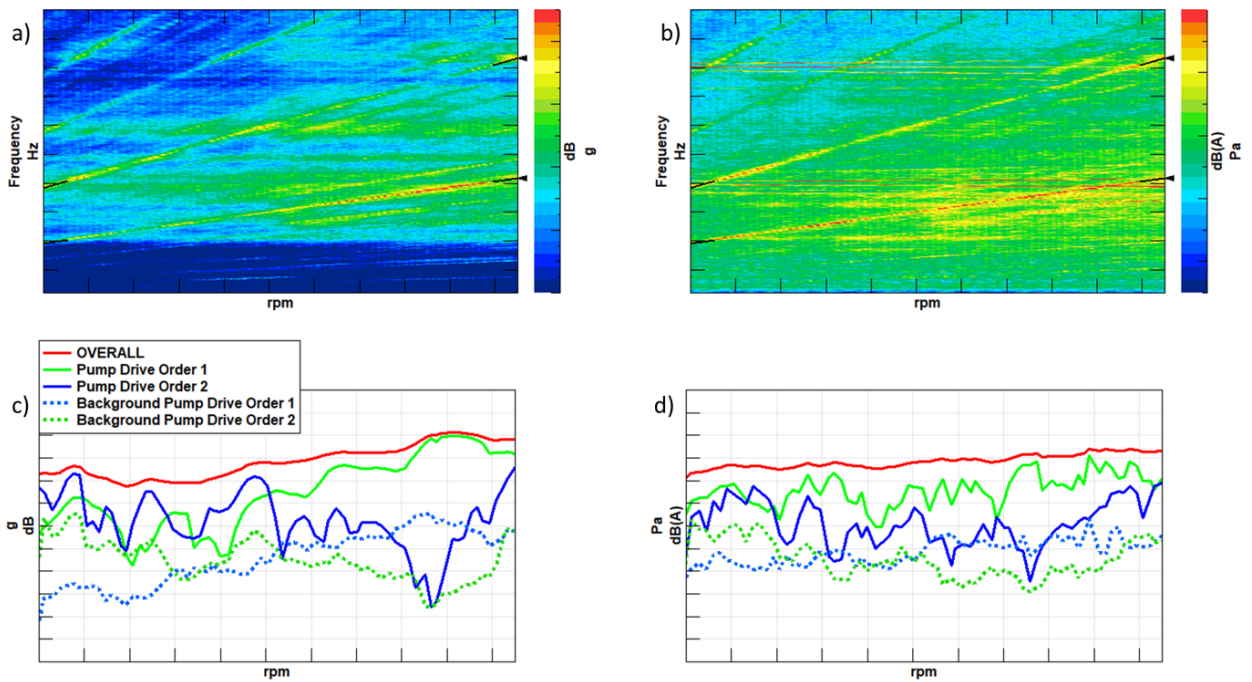


Figure 4: Solid lines represents the pump drive sound pressure level and acceleration orders during run-up test. Dashed lines represents the order related to the background profile

Figure 4 shows the results of the run-up test for either the vibration (a) and the noise level (b). Given that the test room was not an anechoic chamber and there was a high background noise due to the electric motor, fans, and cooling system, we focused on vibrational measurements. At the top, the colormap illustrates the order of the pump drive and its harmonics in dB levels, as the engine speed varies across the displayed frequency range. It is evident that the first and second harmonics of the pump drive play a dominant role in the generation of the overall vibration, significantly accentuated by two resonance zones. In particular, the first harmonic is markedly noticeable at high engine speeds, whereas the second one is more prominent within certain low speed ranges. These results are further supported by figure 4 c) and d). In red, the overall level is depicted, with continuous green and blue lines representing the first and second orders of the pump drive respectively, and their background levels is indicated by dashed green and blue lines. Notably, at high speeds, the first harmonics nearly aligns with the overall vibration level, suggesting the pump drive as the primary vibration source. At lower speeds, peaks of the second harmonics are evident, accentuated by resonances. In this context, the background levels assume a relevant meaning, as the delta values calculated on the harmonics and the overall level exceed acceptable limits.

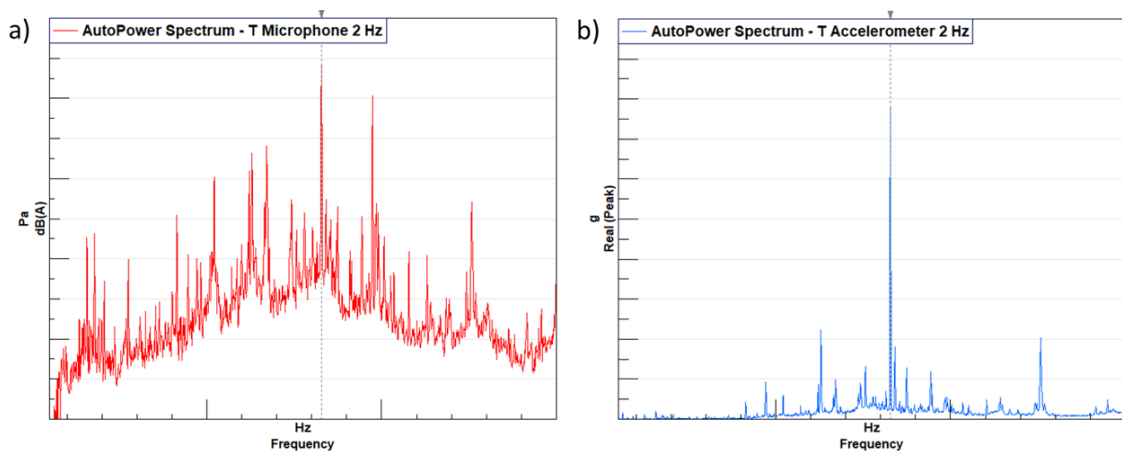


Figure 5: Acoustic and vibration spectrum for Test 2 stationary test

To confirm the evident issue related to the pump drive highlighted by the run-up tests, figure 5 shows the autopower spectrum of the stationary measurements Test 2: a) microphone and b) vibration. It is noteworthy that, in both figures, the meshing frequency of the pump drive, indicated by a black dashed line, is predominant across the entire measured frequency range.

To sum up, the results are off target due to evident levels of criticality concerning our metrics. A new gear design is required in order to improve the NVH performance of the geartrain itself. By employing an NVH digital twin of the real subsystem one may be able to represent the vibrational behavior of the geartrain and evaluate new gear design proposal for vibration and noise reduction. In the next section the dynamic lumped parameter model and the finite element model of the transmission are briefly described. Afterwards, a virtual correlation is performed. Once the reliability of the model has been proved, new design proposal is explored by means of virtual simulation. Finally, the new gear design is experimentally tested, confirming the effectiveness of the overall approach.

### 3 Digital twin set up

In this section a digital twin of the real gearbox is build up by combining LP and FE modeling approach. The LP model allows the estimation of dynamic reaction forces on bearings by starting from gear mesh. The employed model is non-linear and accounts for backlash, time-varying and load-dependent mesh stiffness and load dependent bearing stiffness. In the FE model, only the gearbox casing is meshed, with internal components replaced by concentrated masses connected to bearing housing via rigid elements. The output of the combined model is the acceleration of the gearbox case under specified operating conditions and gear

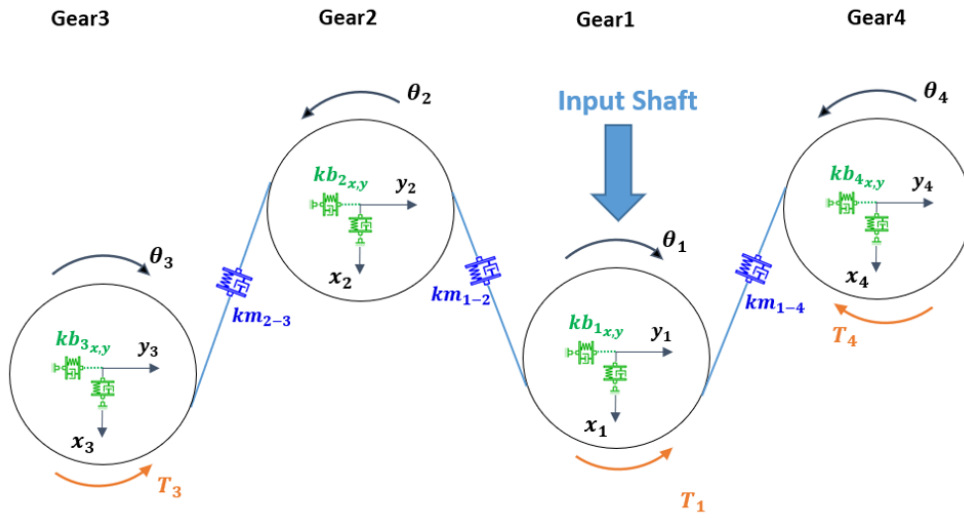


Figure 6: Lumped model for geartrain.  $\theta_i$  is the rotation angle of gear  $i$ .  $T_i$  represents the external torque applied to gear  $i$ .  $kb_{ix,y}$  is the bearing stiffness along  $x$  and  $y$  direction. Finally  $km_{i-j}$  is the meshing stiffness between gear  $i$  and  $j$

layout. The FE model preliminary reliability is verified by performing an experimental frequency response function analysis within the frequency range of interest and comparing the results with numerical point FRF. Subsequently, the validated mesh is used for dynamic analysis, where input forces derived from the LP model are applied to the bearing seats. Experimental assessment is finally conducted through acceleration measurements during operational conditions.

### 3.1 Lumped parameter model

A discrete model of the geartrain is shown in figure 6. Three degrees of freedom are associated to each gear, namely  $\theta_i, x_i, y_i$ .  $\theta_i$  is the rotation around z axis; according to the reference frame, it is positive in counterclockwise direction, while  $x_i$  and  $y_i$  are the radial displacement in x and y directions. The equation governing the motion of the system is:

$$[M]\ddot{x} + f(x_r, x_b) \left[ [C]\dot{x} + [K]x - \frac{1}{2}k_m x_b \right] = F \tag{1}$$

Where

$$f(x_r, x_b) = \begin{cases} 1 & \text{if } x_r > x_b/2 \\ 0 & \text{if } -x_b/2 \leq x_r \leq x_b/2 \\ -1 & \text{if } x_r < -x_b/2 \end{cases} \tag{2}$$

and  $[M]$ ,  $[C]$  and  $[K]$  are the mass, damping and stiffness matrices, respectively;  $x_r$  is the dynamic transmission error;  $x_b$  is the gear backlash;  $k_m$  is the time-varying meshing stiffness;  $\ddot{x}, \dot{x}, x$  are the acceleration, velocity and displacement vectors;  $F$  is the external forces vector. Damping is defined as Rayleigh damping, i.e. proportional to mass and stiffness matrices, so that:

$$[C] = \alpha[M] + \beta[K] \tag{3}$$

Where  $\alpha$  and  $\beta$  are the Rayleigh's damping mass and stiffness proportionality coefficient.

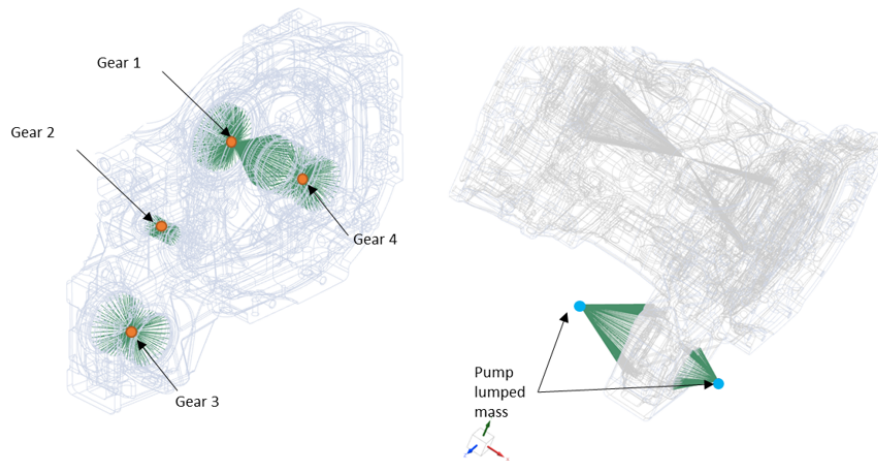


Figure 7: Connection point between LPM and FEM

Various approaches can be adopted for determining the alpha and beta coefficients. Initially, they may be evaluated based on empirical knowledge. Subsequently, they could be refined through calibration against the principal (linearized) resonances of the geartrain, which may be assessed experimentally, for instance. In this study the first option was employed. Gear mesh stiffness is computed by employing the Weber & Banaschek approach. The methodology is applied for various mean values of the torque load, in order to obtain the stiffness value in varying-load conditions. In the same manner, the load-dependent bearing stiffness is computed according to the analytical formulation proposed in [17].

### 3.2 FE model

A finite element method was employed to simulate the vibrational behavior of a gearbox casing due to reaction forces arising from gear meshing. The external casing of the transmission was meshed using 4-node 3D tetrahedral elements whereas the internal components were represented by concentrated masses. These masses were characterized by their center of mass and inertial properties and subsequently linked to the bearing seats via rigid elements. In the same manner, the transmission of reaction forces resulting from gear meshing LP were applied to the center of bearing seat by means of rigid elements, see figure 7. Fixed constraints were applied to the driveline to replicate the actual boundary condition. Based on the author experience a constant damping of 3% has been considered. The structural finite element mesh is validated with the data collected by means of experimental impact testing comparing mode shapes and natural frequencies evaluated numerically through the Nastran solution SOL 103.

## 4 Numerical assessment and results

In this section a numerical experimental correlation on industrial use case shown in Section 2 is proposed. Unfortunately, due to confidentiality of the topic, the authors cannot give any kind of information of the real system specifications. The purpose of this section is to give proof of the accuracy of the model. The coupled FE and LP model is employed to predict the real behavior during the stationary operating condition shown in Section 2, identified as Test 2. As mentioned in the previous section, the FE model preliminary reliability is verified by performing an experimental frequency response function analysis within the frequency range of interest and comparing the results with numerical point FRF. The point chosen for the FRF analysis and the acceleration monitoring are qualitatively depicted in figure 8 b). They represent strategic portion of the driveline involved in the interested modal shapes. A comparison between numerical and experimental outcomes of impact testing are depicted in figure 8 a). The correlation is performed by comparing the acceleration

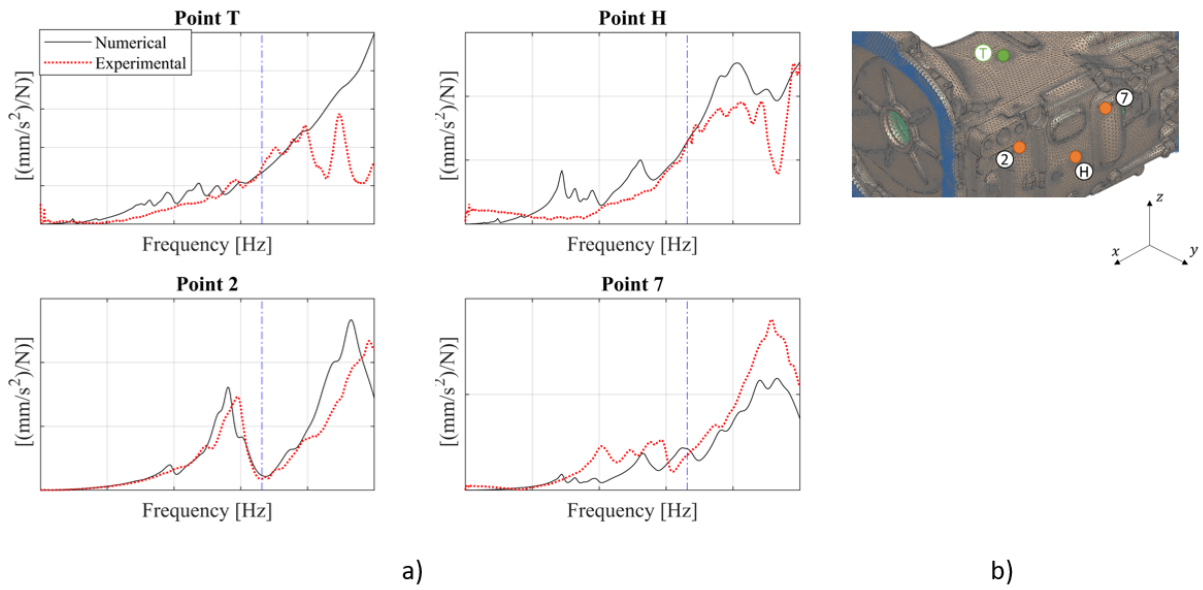


Figure 8: Impact test, FEM correlation. Blue dashed vertical line is related to Test 2 frequency

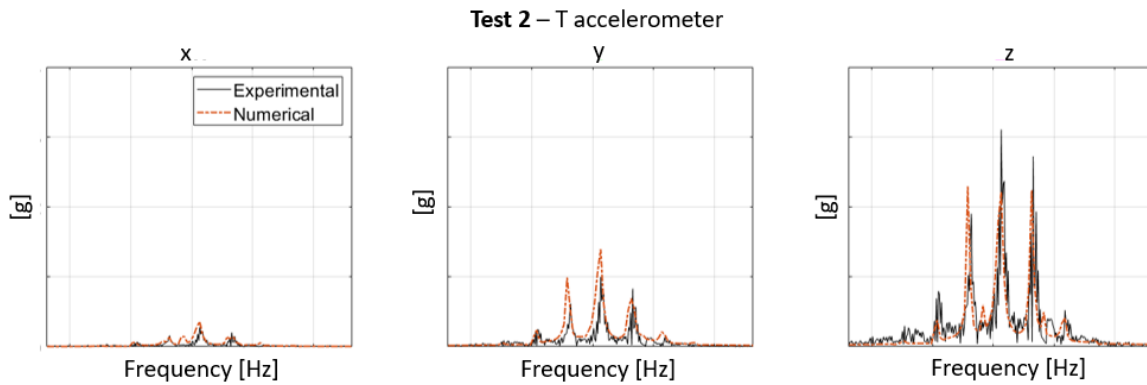


Figure 9: Test 2, coupled FE and LP model correlation

in the point T. It is worth noticing how the numerical signals are in agreement with the experimental ones, ensuring the local reliability of the mesh. Afterwards, the LP model was piloted by a P.I.D. (proportional integral derivative) controller to follow the experimental engine speed profile and was excited with the actual torque load at G4 and G3. Results are compared in figure 9. It is worth noticing how side-bands appear in the frequency response spectrum. This phenomenon is linked to test bench hydraulic brake. In fact, they introduce a slow frequency modulation due to their electronic controller which was not able to maintain a constant torque. Beside this aspect, the numerical outcomes are aligned with the experimental results, proving the reliability of the modeling approach. Once the reliability of the model has been proven, different design configurations have been virtually tested. The detailed explanation of design criteria to reduce the gear whine noise is not the primary focus of this work. Unless this, the authors want to give some qualitative explanation of the design approach adopted to face and control the issue. The peak-to-peak transmission error affects the vibration performance of a geartrain. It is well known in gear design that by decreasing the pressure angle and increasing the helix angle one may produce a reduction of internal dynamic loads by increasing the overall contact ratio. In fact, it has been widely proven that high-contact-ratio gears offer a better NVH performance compared to standard-contact-ratio gears. In addition, microgeometry modification may guarantee a very smooth transmission error for a defined load. In fact, several studies have been conducted

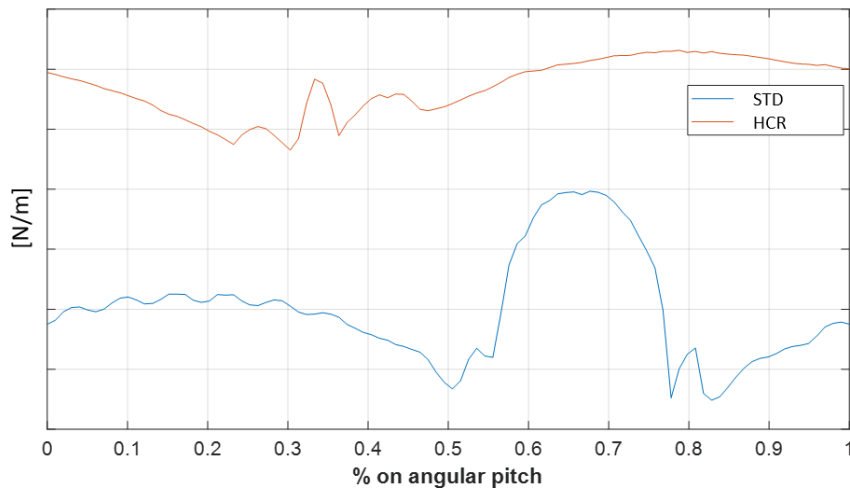


Figure 10: Mesh stiffness profile comparison standard gear (STD) vs high contact ratio gear (HCR)

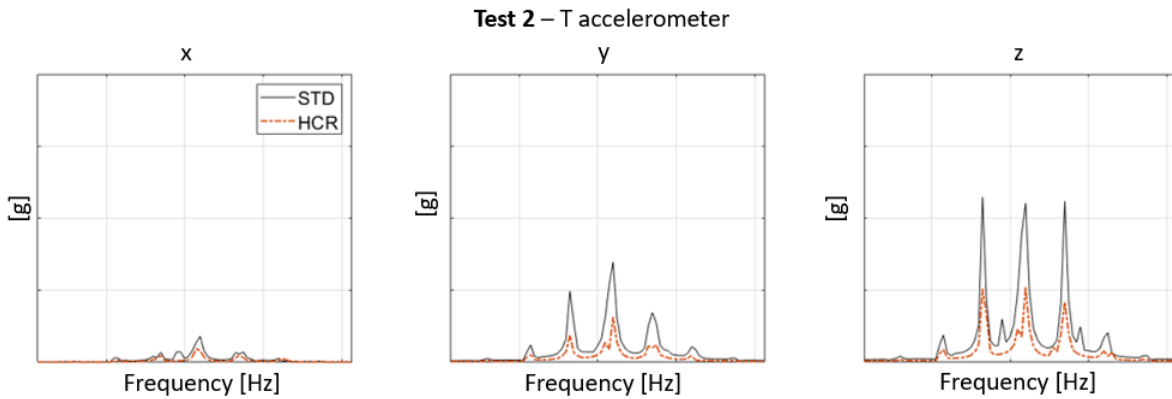


Figure 11: Test 2, numerical results comparison standard gear (STD) vs high contact ratio gear (HCR)

in order to analyze and reduce mesh stiffness and transmission error fluctuations. Gear tooth modification are used to obtain a smooth load transfer and reduce whine noise emission. Litvin and Fuentes detailed the generation of microgeometry in [3] considering spur gears, helical gears, spiral bevel gears, hypoid gears and planetary gear set. By considering the aspect previously described, a new gear design has been released accounting for both new macrogeometry, resulting in High Contact Ratio gears (HCR), and microgeometry. In figure 10 the meshing stiffness of the new design proposal is shown in comparison with the standard one for a certain load. It is worth noticing the smoother trend of the HCR solution, effect of an increased contact ratio and an optimized microgeometry for a given load.

The new gear design (HCR) dynamic response was investigated by employing the NVH digital twin of the driveline. Results are shown in figure 11. The dynamic model shows a significant reduction of acceleration corresponding to “T accelerometer”. It is needed to underline that the acceleration at a given point and the sound pressure level does not have a direct relationship. Unless this, generally, a reduction of the acceleration level implies a reduction of the sound pressure level. The aforementioned findings are confirmed by the experimental results shown in Figure 12. Both the acoustic (a) and vibrational (b) comparisons are highlighted with the STD and HCR configuration represented by the black and dashed red curve respectively. Due to the fact that the tests were not conducted at the exact same motor speed, the pump drive mesh frequency is slightly different; nonetheless, a noticeable reduction in the peak is observed on both the microphone and the accelerometer.

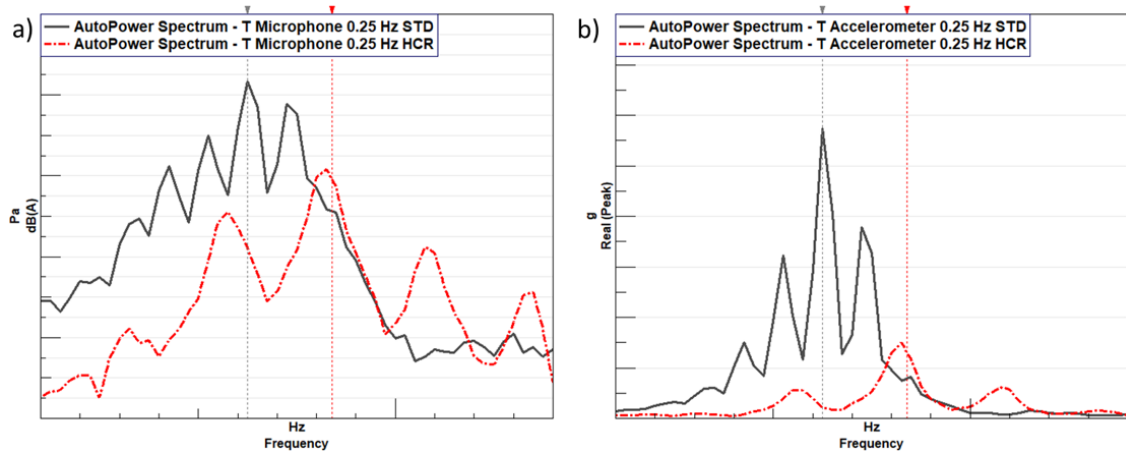


Figure 12: Test 2, experimental results comparison standard gear (STD) vs high contact ratio gear (HCR)

To conclude the experimental evaluation, the new configuration with the HCR is shown in figure 13 on the run-up test for either the vibration (a) and the noise level (b). Figure 13 shares the same structure of figure 4, including the axis ranges, therefore the two configurations can be compared. It can be observed that, in both graphs, the vibration and noise levels have decreased with the HCR configuration when compared to the STD. From the lower graphs (c) and (d), it is evident that the pump drive order, represented by the green curve, is less close to the overall level, represented by the red curve. Additionally, the difference between the background and the harmonics has decreased in the most critical rpm ranges, resulting in the final outcomes falling within acceptable limits.

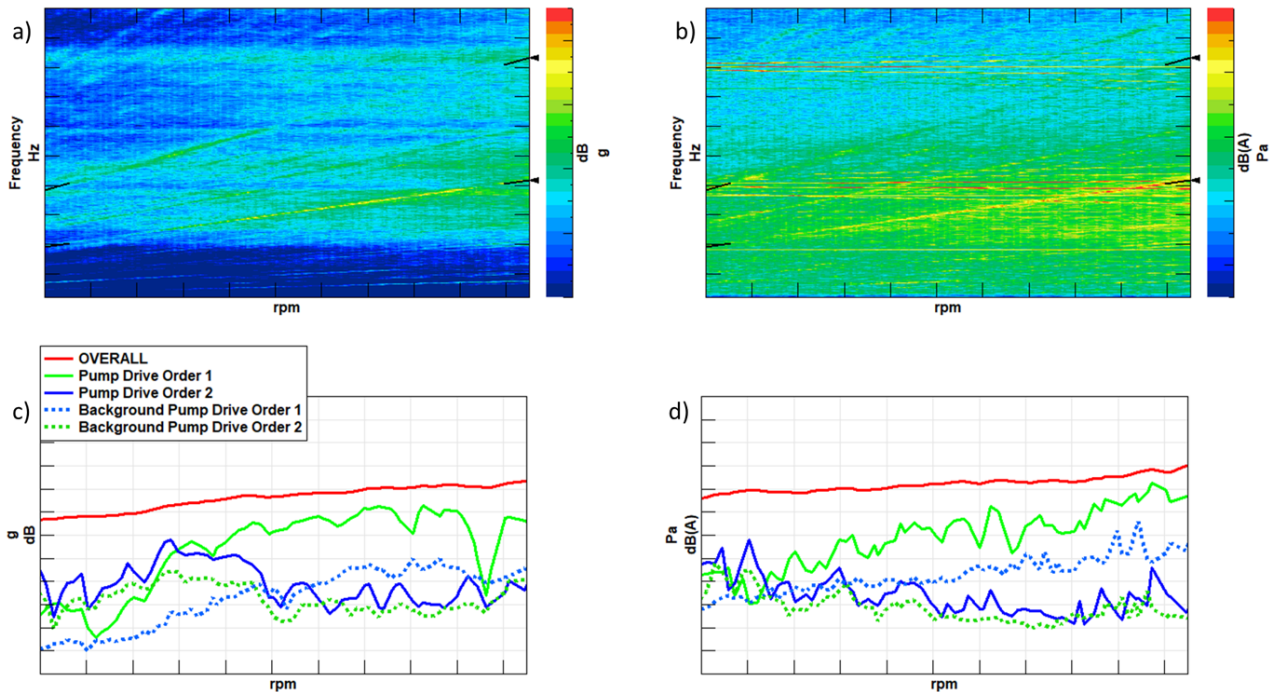


Figure 13: Solid lines represents the pump drive sound pressure level and acceleration orders during run-up test with HCR gears. Dashed lines represents the order related to the background profile

## 5 Conclusion

This paper introduces an NVH digital twin for a real gearbox, utilizing a combination of a lumped-parameter model (LPM) and a structural finite-element model (FEM). By merging these two modeling techniques, the virtual strategy successfully captures the intricate interactions among various components of the agricultural transmission system, such as gears, shafts, bearings, and gearbox housing. Initially, the model was validated with experimental data, ensuring its accuracy in representing the complex dynamics within the transmission system. Following validation, the dynamic model was used to investigate and evaluate different design solutions, focusing on both macro and microgeometry changes. This process aimed to find configurations that could effectively reduce noise emissions while preserving optimal system performance. The methodology outlined in this paper, from dynamic modeling to experimental validation, offers a thorough and effective approach for approaching noise issues in agricultural machinery. It provides a comprehensive understanding of the interactions among different components of the transmission system. Firstly, the experimental characterization is introduced, describing the experimental setup, the metrics used to measure noise and acceleration levels, and the driveline evaluation. Afterwards details the FEM/LPM model and its numerical-experimental validation are given. Finally, the results confirmed the reliability and effectiveness of the overall approach. With this methodology, noise was significantly reduced, demonstrating the practical applicability and advantages of the proposed approach in real-world applications.

## Acknowledgements

The authors wish to express their gratitude to CNH Industries for providing the opportunity to implement this technique, as well as for the logistical support that facilitated its execution. The innovative approach demonstrated by CNH Industries in adopting this methodology is truly commendable.

## References

- [1] H. Walker *et al.*, “Gear tooth deflection and profile modification,” *Engineer*, vol. 166, pp. 409–412, 1938.
- [2] S. L. Harris, “Dynamic loads on the teeth of spur gears,” *Proceedings of the Institution of Mechanical Engineers*, vol. 172, no. 1, pp. 87–112, 1958.
- [3] F. L. Litvin and A. Fuentes, *Gear Geometry and Applied Theory*, 2nd ed. Cambridge University Press, 2004.
- [4] Z. Chen and Y. Shao, “Mesh stiffness calculation of a spur gear pair with tooth profile modification and tooth root crack,” *Mechanism and Machine Theory*, vol. 62, pp. 63–74, 2013.
- [5] H. Ma, X. Pang, R. Feng, and B. Wen, “Evaluation of optimum profile modification curves of profile shifted spur gears based on vibration responses,” *Mechanical Systems and Signal Processing*, vol. 70–71, pp. 1131–1149, 2016.
- [6] H. N. Özgüven and D. R. Houser, “Mathematical models used in gear dynamics—a review,” *Journal of sound and vibration*, vol. 121, no. 3, pp. 383–411, 1988.
- [7] A. Kubo, K. Yamada, T. Aida, and S. Sato, “Research on ultra high speed gear devices,” *Trans. Jpn. Soc. Mech. Eng.*, vol. 38, pp. 2692–2715, 1972.
- [8] K. Umezawa, T. SATO, and J. ISHIKAWA, “Simulation of rotational vibration of spur gears,” *Bulletin of JSME*, vol. 27, no. 223, pp. 102–109, 1984.
- [9] F. Kucukay, “Dynamic loads in gear teeth,” in *Proceedings of the Third Conference on Vibrations of Rotating Machinery, Institution of Mechanical Engineers*, vol. 306, 1984, pp. 73–79.

- [10] A. Kahraman and R. Singh, "Non-linear dynamics of a spur gear pair," *Journal of sound and vibration*, vol. 142, no. 1, pp. 49–75, 1990.
- [11] A. Kahraman and R. Singh, "Non-linear dynamics of a geared rotor-bearing system with multiple clearances," *Journal of sound and vibration*, vol. 144, no. 3, pp. 469–506, 1991.
- [12] A. Kahraman and R. Singh, "Interactions between time-varying mesh stiffness and clearance nonlinearities in a geared system," *Journal of Sound and Vibration*, vol. 146, no. 1, pp. 135–156, 1991.
- [13] A. Gabrielli, F. Pizzolante, E. Soave, M. Battarra, C. Mazzeo, M. Tarabra, E. Fava, and E. Mucchi, "A numerical model for nvh analysis of gearboxes employed on agricultural equipment," in *ISMA 2020 International Conference on Noise and Vibration Engineering Online Proceedings*, 2020, pp. 3191–3203.
- [14] F. Pizzolante, M. Battarra, E. Mucchi, and B. Cochelin, "Combining the asymptotic numerical method with the harmonic balance method to capture the nonlinear dynamics of spur gears," *Mechanical Systems and Signal Processing*, vol. 214, p. 111384, 2024. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0888327024002826>
- [15] F. Pizzolante, M. Battarra, G. D'Elia, and E. Mucchi, "A rattle index formulation for single and multiple branch geartrains," *Mechanism and Machine Theory*, vol. 158, p. 104246, 2021. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0094114X21000045>
- [16] F. Pizzolante, M. Battarra, and E. Mucchi, "The role of gear layout and meshing phase for whine noise reduction in ordinary geartrains," *Mechanism and Machine Theory*, vol. 181, p. 105209, 2023. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0094114X22004542>
- [17] T. A. Harris and M. N. Kotzalas, *Advanced concepts of bearing technology: rolling bearing analysis*. CRC press, 2006.