TORSIONAL VIBRATION SYMPOSIUM

PROGRAM SALZBURG 2022

Content

Dear Colleagues,

Time flies: It has already been five years since the second Torsional Vibration Symposium was held here in Salzburg. Now, we are very pleased to welcome you to the third Torsional Vibration Symposium from May 11-13, 2022!

We are again looking forward to welcoming torsional vibration experts from all around the globe, and to hearing lectures on a wide array of topics. In 2017, this special meeting for torsional vibration experts attracted 186 participants from more than 20 countries. At that time, 36 papers were presented, and we are happy to say that the event has only been expanding! This year, we have more than 50 presentations on groundbreaking ideas presented in the newest papers. And even though travelling is still more complicated than it used to be, we expect more than 200 participants from 25 countries all around the world.

Being responsible for the conference, we would like to thank all of the authors for their contributions to the event and for their efforts to make the program so complete. The exchange of knowledge and information between torsional vibration experts from universities, research institutes, consulting companies, software- and measurement companies and from the industry is of major significance to all of us. However, the conference does not only aim to contribute to the technical and scientific progress in the field of torsional vibrations, but also to improve the cooperation between people within this field.

We are looking forward to this third Torsional Vibration Symposium and we hope that you will enjoy it!

Sincerely yours,
Uwe Merl and Lothar Kurtze

Schwingungstechnischer Verein

TORSIONAL VIBRATION SYMPOSIUM

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Organization

The organizer of the event is the Vibration Association.

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Schwingungstechnischer Verein

Schwingungstechnischer Verein
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Program

Wednesday: May 11, 2022

18:00	Welcome reception, Restaurant M32

Thursday: May 12, 2022

07:30	Registration desk opens
09:00	Official opening
09:15	Keynote: Prof. KangKi Lee Senior Vice President of HPS, AVL List GmbH, Graz, Austria **To move forward the green way by which the Internal Combustion Engine can meet the zero carbon ambition**
10:00	Coffee break, exhibition opens

	Session 1A: Engine Development	Session 1B: System Reliability
10:30	**Beyond cranktrain dynamics** B. Mokdad, S. Clot, H. Bruns, K. Buczek, M. Bartosik Liebherr Components Colmar SAS, FEV Europe GmbH, FEV Polska Sp. z o.o.	**Observation of torsional vibration with RENK VIB-monitor system** C. Wengert, A. Kania, W. Sigmund Renk GmbH
10:55	**Anti-vibration design of multi-cylinder engines considering torsional vibration characteristics** K.H. Jung, Y.J. Jo, J.W. Kim, J.W. Choi, M.K. Shin, H. Choi, J.D. Yu Hyundai Heavy Industries	**Solving gear problem with flexible coupling under thruster excitation** M. Hasan, P. Sundström, R. V. Laarhoven, S. V. Heesbeen CENTA a brand of Regal Rexnord Corp., Wärtsilä Finland Oy, Wärtsilä NL
11:20	**Study of torsional vibration characteristics of a six cylinder diesel engine under cylinder deactivated conditions** B. Mahanta, I. Piraner Cummins Inc.	**Engine crankshaft failures due to torsional natural frequency excited by dual fuel operation** T. Feese, G. Beshouri Engineering Dynamics Incorporated, Advanced Engine Technologies Corporation
11:45	Lunch	

	Session 2A: Powertrain Components – Elastic Couplings and Dampers I	Session 2B: System Reliability – Case Studies
13:00	**Highly elastic elastomer couplings – Indescribably complex?** M. Dylla VULKAN Deutschland	**Motor cooling fan failures solved with modal and finite element analyses** T. Feese, J.Y. Park, D.J. Lee, Y.J. Jang Engineering Dynamics Incorporated, Samsung Engineering Co. Ltd.
13:25	**Nonlinear frequency dependent stiffness of rubber coupling under shear in real world applications** M. Hasan, R. Zadoks (retired) CENTA a brand of Regal Rexnord Corp., Caterpillar Inc.	**Torsional vibration on rotating machines in oil & gas industry and power gen industry: A review of real cases** N. Péton, J. Yu, S. Ganesh, R. Seshadri, S. Ramanathan Bently Nevada
13:50	**On recent developments for simulations and measurements of torsional elastic steel spring couplings** K. Windhofer, A. Thalhammer Geislinger GmbH	**Grid interaction phenomena in the energy production sector** F. Petit, S. Grégoire, F. Gonzalez, F. Verbinnen ENGIE Laborelec
14:15	**Impact of application-specific thermal conditions on viscous damper lifetime** M. Steidl, R. Zadoks (retired), P. Kamasz, J. Xu Hasse & Wrede, Caterpillar Inc.	
14:40	Coffee break	

	Session 3A: Power System Simulation I	Session 3B: Measurement and Monitoring
15:05	**System approach to lower dynamic loads during resonance pass of a torsional vibration reduction system** F. Liebst, M. Geilen, P. Prystupa, S. Bindig ZF Friedrichshafen AG, GAT – Gesellschaft für Antriebstechnik GmbH	**Is what is measured the real value? Mechanical systems measurement philosophy and principles** M. Zeid BERG Propulsion

15:30	**Analysis and data management of torsional vibration calculation for variant and sensitivity studies** J. Wolter, P. Böhm, A. Rieß, M. Heinrich MAN Energy Solutions SE	**Investigation of gearbox condition monitoring using low-fidelity sensors** M. Rothemund, M. Fromberger, M. Otto, K. Stahl FZG, TU München
15:55	**Creating innovative drivetrain concepts by use of agile model-based development methods** B. Juretzki IME Aachen GmbH Institut für Maschinenelemente und Maschinengestaltung	**Using non-contacting magnetostrictive sensors to measure torsional vibration responses in electric machinery** B. Howard, D. O'Connor, L. Turnbeaugh, C. McMillen Bently Nevada
16:20	Coffee break	

	Session 4A: Compressors	Session 4B: Drilling and Fracturing
16:45	**Torsional failures in hydrogen reciprocating compressor system with stepless capacity control** T. Feese, D.J. Lee, J.Y. Park Engineering Dynamics Incorporated, Samsung Engineering Co. Ltd.	**New insights in torsional vibrations in downhole drilling systems** V. Kulke, D. Heinisch, A. Kück, H. Reckmann, G.-P. Ostermeyer, A. Hohl TU Braunschweig, Baker Hughes
17:10	**Torsional damping benefits for reciprocating compressors** T. Stephens, C. Yeiser, K. Prenninger Ariel Corporation, RBTS, Salzburg University	**New approach of modeling drill bit dynamics** F. Schiefer, G.-P. Ostermeyer, M. Ichiaoui TU Braunschweig
17:35	End of Thursday's sessions	
18:30	Aperitif, Salzburg Residence Palace	
19:30	Gala Dinner, Salzburg Residence Palace	

Friday: May 13, 2022

08:00	Registration desk opens	
	Session 5A: Hybrid and Electric Drives	Session 5B: Powertrain Components – Elastic Couplings and Dampers II
09:00	**Optimizing electric drives for future demands and applications** C. Priestner, I. Garcia de Madinabeitia Merino, J. Pohn, J. Garmendia, M. Mehrgou AVL List GmbH	**Novel approach on thermo-mechanical coupled simulation and validation in rubber couplings** M. Hasan, R. Zadoks (retired) CENTA a brand of Regal Rexnord Corp., Caterpillar Inc.
09:25	**Torsional vibration calculations for hybrid drives** M. Schuchardt, P. Hinkelmanns-Stürzl Rolls-Royce Solutions GmbH	**Calculation of stationary temperature of rubber damper based on torsional vibration analysis of internal combustion engine** T. Parikyan, T. Kovacic, L. Jordan, M. Mulmann, S. Bonù AVL List GmbH, AUDI AG, AGLA Power Transmission S.p.a.
09:50	**PHEV driveline reverse engineering and torsional vibration study during engine restart and booming maneuver** T. Enault, J. Deleener Siemens Industry Software NV	Session 5B: Rules and Regulations **Marine propulsion – Revised class rules for passing barred speed range** E. Brodin, J. O. Nøkleby, H. Amini, S. Avanesov, O. Deinboll DNV GL – Maritime
10:15	**VFDs – How to prevent them from destroying your torsional system** M. A. Corbo No Bull Engineering, PLLC	**CIMAC Working Group 4, Crankshaft rules – Who we are, what we do** P. Böhm, A. Rieß, T. Frondelius, J. Könnö, J. Dowell, D. Bell, Y. Hanawa MAN Energy Solutions SE, Wärtsilä Corporation, Wabtec Corporation, Ricardo UK Ltd., Kobe Steel Ltd.
10:40	Coffee break	

	Session 6A: Measurement and Validation	Session 6B: Noise, Vibration, Harshness (NVH)
11:05	**System requirements for torsional vibrations signal processing** G. Sikora, M. Dereszewski Gdynia Maritime University	**An experimental set-up to investigate engine gear rattle problems** A. Kahraman, A. Donmez Department of Mechanical and Aerospace Engineering, The Ohio State University
11:30	**Monitoring of transient torsional vibrations on a generator shaft in a high-power laboratory** D. Rouwenhorst, J. Hermann IfTA Ingenieurbüro für Thermoakustik GmbH	**Overall powertrain analysis: NVH and RDE in combination** D. Höfler, S. Maxl, F. Senn, F. Burgstaller Tectos GmbH
11:55	**Rotational energy harvester for supplying self-sufficient sensor systems** M. Matthias, M. Gerhardt, M. Weber, M. Koch, T. Bartel Fraunhofer LBF	**Innovative solutions to reduce the transfer of structure borne noise in the powertrain of mega yachts** L. Kurtze Vibration Association
12:20	Lunch	

	Session 7A: Marine Propulsion	Session 7B: Power System Simulation II
13:20	**Torsional vibration monitoring of large container vessel propulsion train** H. Ohorn, A. Thalhammer, H. Mohr CPO Containerschiffreederei, Geislinger GmbH, GasKraft Engineering	**Comprehensive torsional simulation of generator sets – Part I: Calculation of torsional maps** B. Mokdad, C. Henninger, J. Keske Liebherr Components Colmar SAS, Liebherr Machines Bulle SA, Kohler Co.
13:45	**How do the merits of iCER for engine performance affect torsional vibrations?** P. Rebholz, D. Schäpper Winterthur Gas & Diesel Ltd., Chord X Pte. Ltd.	**Comprehensive torsional simulation of generator sets – Part II: Capturing armature core twist of alternator rotor assemblies in torsional models** J. Keske, B. Mokdad, C. Henninger Kohler Co., Liebherr Components Colmar SAS, Liebherr Machines Bulle SA

14:10	**Marine propulsion shafting excessive torsional vibrations: Case studies** B. Cowper, Z. Schramm LamaLo USA, LLP	**Torsional elasticity of flange contact using finite element method** S. Virta Winterthur Gas & Diesel Ltd.
14:35	**Effect of heavy flywheel for torsional vibration on shaft alignment** T. Mitsukiyo Mitsui E&S Machinery Co. Ltd.	**Illustrating the benefits of a torsional vibration damper for eliminating the barred speed range by using hybrid finite element modelling methods** C. Leontopoulos, O. Vlachos, K. Prenninger, A. Thalhammer ABS, Salzburg University, Geislinger GmbH
15:00	Coffee break	

	Session 8: Digital Twin
15:25	**Digital twin of induction motors for response analysis of electric drive trains** T. P. Holopainen, T. Ryyppö ABB Motors and Generators
15:50	**Application of digital twin technology on torsional vibration systems** C. Pestelli, F. Degano, P. Sundström, M. Almerigogna Wärtsilä Corporation

	Session 9: Closing session
16:15	**New opportunities of big data analytics for torsional vibration analysis** A. Thalhammer Geislinger GmbH
16:40	Closing
16:50	End

Saturday: May 14, 2022

08:45	Social and Cultural program

Keynote speaker

The keynote speech will be held by
Prof. KangKi Lee.

Senior Vice President,
High Power Systems,
AVL List GmbH,
Graz, Austria

Professor Kang-Ki Lee is currently working as Senior Vice President at AVL List GmbH in Austria. He is responsible for the business of High Power Systems, e.g. Marine, Power Plant or Locomotives.

Until 1995, he studied Mechanical Engineering. By taking part in different programs, like the Advanced Industrial Program at Seoul National University in 2007 and the executive management course by the MAN Group in cooperation with WHU, Germany and Saïd Business School (Oxford University), he was able to gain management skills in addition to his technical knowledge.

He worked as president of MAN Diesel & Turbo Korea Ltd. and was responsible for the business of internal combustion engines on various applications. Until 2012 Professor Lee was also the head of turbo machinery business units at MAN for Far East Asia. Following, he served as EVP of Daewoo SEC where his responsibilities ranged from business development to global sales and marketing. Until 2018, he was a professor at Korea Maritime & Ocean University, teaching internal combustion engine and power systems.

His research interests range from ICE P&E, Decarbonization and alternative fuels to CSS and future technology of logistics and transportation. Professor Lee was the business leader of the world's first LNG fuelled ship development for Northern America and developed the concept for the largest LNG fuelled bulk carrier upon IMO OGF Code. Currently, he is working as vice-chair of CIMAC GHG Strategy Group, Go-LNG (Baltic Sea), NeLT and Kormarine Committee etc.

Abstracts

Thu	09:15	Karajan Hall	Keynote speech

To move forward the green way by which the Internal Combustion Engine can meet the zero carbon ambition

Prof. KangKi Lee
Senior Vice President of HPS, AVL List GmbH, Graz, Austria

Greenhouse gas emissions are still the most dominant issue in mitigating climate change, resulting in disruptive technology changes until 2050. They will offer a platform to share our views on strategies for sustainable CO2 reduction which will impact the future of all large engine applications. We are currently experiencing a period of high uncertainty in our industry and have tried to get a better understanding of the various aspects of decarbonization, what it means for our industry and whether our strategy is going in the right direction or is to be changed by the impact of COVID-19 and geopolitical disruptions. Some impacts of the current pandemic will change the global power sector as well as transportation and the way we do business in the future. Decarbonization requires our immediate action to meet the 2050 GHG emission reduction targets. No doubt the complete subject of energy transition and emission reduction has the biggest impact both on our business as well as on society in general. The message could be the Internal Combustion Engines (ICE) today providing power for the majority of transportation and mobility solutions covering a wide range of engine applications, such as ships, power plants, oil field services, locomotives and off-road machinery, has a future via net zero carbon fuels which will require different combustion concepts and operation modes. Therefore, related torsional vibration topics still need to be considered. In deep-sea shipping, the IMO GHG reduction goals of CO2 emissions with -40% by 2030 and -70% by 2050 require the integration of operational and technical solutions to improve the energy efficiency of various systems on board. In addition to the introduction of new fuels like green ammonia, hydrogen enriched slush LNG or methanol there will be the need to consider Power-to-X fuels, carbon capture and exhaust gas aftertreatment systems in a life cycle cost assessment.

So, what does this mean for decarbonization of ICE and where are we now with the current readiness of the engine technologies for each of the main fuel candidates? With the state of art technology in terms of efficiency, the transition will be in the fuels. When we look for the horizon of GHG 2050, (Net) Zero carbon fuels represent the most promising energy carrier option for the future ICE applications. This means that ICE still needs to be developed for the fuel flexibility. It would be nice if we would have qualitative statements for alternative fuels with regard to their implication on torsional vibration.

What would be interesting in terms of "torsional vibrations";

- Strategy drivers of GHG reduction are fuels, technologies and policy.
- Different fuels influence cylinder pressure in a different way what results in different dynamics
- Combustion influences TV behavior – excitation force.
- Different gaseous fuel result in different combustion concepts, which will result in a different vibration characteristic.
- In case of H2, combustion become sensitive and higher excitation force can be expected. Ref. To study of Munich University.
- Gaseous fuels likely induce higher fluctuations and combustion instability due to the nature of their combustion behavior.
- Skip firing affects TV behavior, dynamics will be different i.e. higher peaks and irregularity increase.
- Decarbonization strategy may be to go for slow steaming, many ships will choose slow steaming which can cause operation in an RPM range with higher torsional vibration levels

The journey where we are on regarding the-state-of-art-technology and fuels flexibility and where we are heading for is posing the question what is the pathway towards GHG2050 and decarbonization? What would be the role of the various stakeholders: Legislators, Users, Builders, Technology providers?

The way for regulators and policy makers to drive changes will have to take into consideration the concerns of the public regarding the climate change issue and a consistent approach to a sustainable CO2 reduction by using state of the art technology with the highest efficiency over the full life cycle.

Thu 10:30 Karajan Hall Engine Development (1A)

Beyond cranktrain dynamics

B. Mokdad, S. Clot, H. Bruns, K. Buczek, M. Bartosik
Liebherr Components Colmar SAS, FEV Europe GmbH, FEV Polska Sp. z. o. o.

Modern high-speed engines are designed to overcome severe excitations coming from gas and mass forces and moments. On the one hand, gas forces are the result of increasing peak firing pressure to fulfill more and more restrictive emission legislations. On the other hand, rotating and oscillating mass forces are speed dependent and their related excitations are thereby getting higher.
Cranktrain dynamics simulation is well established at the Liebherr group by means of 1D torsional vibration simulation in frequency domain as well as detailed 3D Multi-Body Simulation using FEV Virtual Dynamics software. This results in the load cases to be used for crankshaft durability assessment. This simulation workflow allows a better understanding of influencing parameters, such as firing sequence and crankstar, and accordingly optimize cranktrain and engine performances. However, the effect of cranktrain dynamics on crankcase and its attached components is not well understood and not enough explained in literature.
In this contribution, theoretical and experimental demonstration on how severe excitation of torsional and axial cranktrain dynamics caused by major engine orders are transmitted, via the main bearings, to the crankcase and then to static engine components. In the case of critical situation, some solutions will be proposed and discussed.

Thu 10:55 Karajan Hall Engine Development (1A)

Anti-vibration design of multi-cylinder engines considering torsional vibration characterstics

K.H. Jung, Y.J. Jo, J.W. Kim, J.W. Choi, M.K. Shin, H.J. Choi, J.D. Yu
Hyundai Heavy Industries

Torsional vibrations in marine engine are considered important in terms of crankshaft durability design. Recently, vessels and engines are becoming lighter together with stricter environmental regulation. Hence multi-cylinder engine stiffness is getting less whereas engine excitation force is getting higher. Therefore, it is likely that high structural vibration happens due to engine force so called guide force giving a major impact on engine structures in forms of moments – either H or X moments. It is also known that vibratory torque due to torsional vibration also induces additional X-moment in engine. Cases of structural vibration due to torsional mode with nodal point inside the crankshaft have been reported for multi-cylinder engine with more than seven cylinders. For engines with less than six cylinders, the torsional mode of the crankshaft exists generally away from engine operating range.
This study describes the importance of torsional vibration to be considered at engine design stage and suggests counter-measures to them through reference cases for 2 stroke marine diesel engine.

Thu 11:20 Karajan Hall Engine Development (1A)

Study of torsional vibration characteristics of a six cylinder diesel engine under cylinder de-activated conditions

B. Mahanta, I. Piraner
Cummins Inc.

Cylinder deactivation technology has shown potential benefits in terms of improved efficiency and after treatment thermal management in diesel engines. One of the primary challenges of using cylinder deactivation methodology is the resulting change in torsional vibration signature of the engine which might cause low frequency resonances in operating speed range and deteriorate the overall NVH characteristics of the vehicle. This paper documents the procedure developed to analytically study the effect of cylinder deactivation on the torsional vibration signature of a diesel engine. In cylinder deactivation mode with cylinder valves closed, the cylinder pressure in the deactivated cylinders would vary every engine cycle as the cylinders bleed and then subsequently recharged. This cycle varying phenomenon would call for a time domain dynamic analysis solution to evaluate the torsional vibration response. However, the process would be still be periodic, but with period equal to 'n' engine cycles. Since frequency domain analysis has some advantages over time domain analysis, the standard frequency domain analysis tool was modified to calculate the response for a 'n' cycle period instead of standard 720 degrees cycle period. What is novel about this method is that it can be used to calculate the frequency response for various patterns of cylinder deactivation which may not be periodic over a 720 degrees cycle, but over 'n' cycles. This enables to effectively study the dominant orders of vibration as it changes with various patterns of cylinder deactivation and optimize deactivation patterns based on the torsional vibration response of the system.

Thu 10:30 Wolf-Dietrich Hall System Reliability (1B)

Observation of torsional vibration with RENK VIB-monitor system

C. Wengert, A. Kania, W. Sigmund
Renk GmbH

Marine propulsion systems are highly complex systems, which can combine different prime movers such as diesel engines, gas turbines and electric motors. Operational reliability and machinery availability are important requirements for these propulsion systems.
Therefore, RENK developed a condition monitoring system (RENK VIB-Monitor). This system continuously monitors high dynamic vibration, shaft movement and torque measurements, as well as different process parameters such as speed, temperature or pressure. Based on an automatic analysis, overloads and torsional vibrations can be detected and prevented. The source of vibration excitation can be identified by means of automatic frequency allocation and appropriate software tools for detailed signal assessment. Additionally, condition monitoring systems allow you to detect arising wear phenomena and to avoid subsequent fatal failures. Besides an introduction of the condition monitoring functionality, two practical examples of abnormality detection are presented on naval ships with the help of condition monitoring systems.

Thu 10:55 Wolf-Dietrich Hall System Reliability (1B)

Solving gear problem with flexible coupling under thruster excitation

M. Hasan, P. Sundström, R. V. Laarhoven, S. V. Heesbeen
CENTA a brand of Regal Rexnord Corp., Wärtsilä Finland Oy, Wärtsilä NL

A real-time monitoring in vessel is used to understand the root cause of several gear failures. The elastic coupling is installed to attenuate the dynamic vibratory torque in gear input shaft. The magnification of vibration is observed under blade pass frequency (BPF). We have investigated the higher order blade pass frequencies as well as gear mesh vibratory amplitudes in order to characterize the response of driveline under thruster excitations. A torsional vibration analysis was conducted in the design stage. It is a key challenge to incorporate the accurate propeller excitation models for higher order blade pass frequencies. The mass moment of inertia of propeller in immersed condition and the damping values of ducted propeller have a noticeable influence on the magnitude of vibratory torque in shaft line. We conducted a ramp-up measurement with elastic coupling. It shows a high reduction of second blade pass frequency intensity in all thrusters. Particular attention was paid to investigate the vibration signature of driveline with and without elastic couplings. We observed from measurement that the first two natural frequencies control the vibration and influence the gear input shaft vibratory torque. It is extremely important to capture the amount of allowable vibratory torque in gearbox input shaft in order to solve the gear failure issue. The coupling provides an evidence of a higher system reliability from test.

Thu 11:20 Wolf-Dietrich Hall System Reliability (1B)

Engine crankshaft failures due to torsional natural frequency excited by dual fuel operation

T. Feese, G. Beshouri
Engine Dynamics Incorporated, Advanced Engine Technologies Corporation

Two diesel engine-generator systems were originally built and certified for emergency power at a nuclear power plant. Now these systems are being used for continuous power generation in South America. The engines were converted by the OEM to operate on dual fuel due to reduced energy cost of natural gas using the OEM's obsolescent dual fuel technology. Two failures of the engine crankshafts have occurred after the conversion. In both instances, spiral cracks occurred in the engine crankshaft between throws 7 and 8 (flywheel end), which is indicative of high torsional vibration. Through torsional analysis and field measurements, the root cause for the crankshaft failures was found to be excitation of the first torsional natural frequency (TNF) by the 4th engine order. When operating on diesel fuel, for which the units were originally designed and tested, the 4th engine order is low amplitude and stable. However, when operating in dual fuel mode, the 4th engine order varies considerably in amplitude and can be quite high. Measured pressure traces showed increased variation with dual fuel versus diesel. The difference in excitation created by dual fuel versus diesel combustion, coupled with the generally stochastic nature of gaseous combustion, results in excitation at the 4th engine order that had not been previously recognized.

Thu	13:00	Karajan Hall	Powertrain Components I (2A)

Highly elastic elastomer couplings – Indescribably complex?

M. Dylla
VULKAN Deutschland

That elastomers show nonlinear material behaviour is not a new insight. Already since the middle of the 20th century, there have been numerous publications dealing with material behaviour. Nevertheless, there is always uncertainty regarding the use of the correct coupling parameters in the calculation models. The transfer behaviour of the system components involved is necessary for calculating the stationary and transient operating behaviour. The pronounced elastic (and damping) properties of elastomer couplings significantly determine the dynamic behaviour of the drive train.
The common calculation methods used in industrial practice assess the dynamic load in a drive train based on stationary, harmonically excited operating states. For this purpose, a linear transmission behaviour of the system components is required. Since a linear transmission behaviour is often not given in practice (backlash-free gears, constant hydrodynamic masses on the propeller, ...), it is usual to use operating-point-related characteristic values. This also applies to highly elastic elastomer couplings with their characteristics characterized by nonlinear material behaviour.
A major challenge now is to meet the demand for a safe, practice-oriented selection method. For this purpose, it makes sense to limit the possible range of the load variables to a value range that is necessary for the general and predominant number of application cases.
Which are the influencing factors? Where do the discrepancies between published values and measurement experience come from?

Thu	13:25	Karajan Hall	Powertrain Components I (2A)

Nonlinear frequency dependent stiffness of rubber coupling under shear in real world applications

M. Hasan, R. Zadoks (retired)
CENTA a brand of Regal Rexnord Corp., Caterpillar Inc.

Even though the torsional response of rubber couplings is nonlinear under harmonic vibrations, manufacturers traditionally publish dynamic stiffness values that correspond to the behavior when the coupling is subjected to vibrations at 10 Hz. To improve the prediction of these dynamic stiffness values, simulation models were developed to compute the static stiffness of elastomer couplings under zero frequency using a Finite Element Analysis (FEA) code. This approach led to predictions of higher dynamic stiffness values, which are in line with previously published results.
To achieve higher operational reliability of drivelines, the nonlinear behavior of elastomer couplings needs to be accurately characterized, particularly when a coupling is simultaneously subjected to several significant components of vibration at different frequencies. By comparing test results under single (on a bench) and multiple (in a driveline with a reciprocating engine) frequency excitation, it was found that there was a significant difference in the apparent torsional coupling stiffness. This indicated that there are strong nonlinear interactions of dynamic stiffness as a function of amplitude, preload, and the frequency for each component of harmonic excitation. In particular, the interaction of amplitude with frequency has a remarkable influence under irregular operating condition, as the apparent coupling stiffness is significantly different when compared to results under regular operating conditions. Simulation results were compared with measured data, resulting in a good match.

Thu 13:50 Karajan Hall Powertrain Components I (2A)

On recent developments for simulations and measurements of torsional elastic steel spring couplings

K. Windhofer, A. Thalhammer
Geislinger GmbH

Extensive simulation studies at an early project stage and long-term measurements on real-life applications are both essential for dimensioning and servicing during the whole lifetime of torsional elastic couplings. In this paper, recent requirements and developments for both aspects are discussed, where - more specifically - new time-domain simulation models and torsional vibration (TV) monitoring opportunities for torsional elastic steel spring couplings are presented. For the simulation part, it is shown how classical, steady-state models can be transferred to the time-domain and the benefits of performing transient TV calculations are illustrated with simulation studies, where the design of the coupling can be further optimized by transient simulations. In the measurement section, a new cloud-based data processing architecture for TV monitoring is discussed, with which new requirements of recently developed measurement analysis methods can be handled.

Thu 14:15 Karajan Hall Powertrain Components I (2A)

Impact of application-specific thermal conditions on viscous damper lifetime

M. Steidl, R. Zadoks (retired), P. Kamasz, J. Xu
Hasse & Wrede, Caterpillar Inc.

Degradation of silicone fluid, and thus the lifetime of viscous dampers, is determined by the temperature history of the fluid. Efforts have been made in the recent past to increase the simulation accuracy of the silicone fluid temperature (e.g. taking into account the three-dimensional fluid temperature field). However, the fluid temperature is determined by quantities which are not all under the control of the damper manufacturer. For example, the heat transfer coefficient of a viscous damper is not a damper-specific quantity. Application-specific ambient conditions also play a major role, e.g. ambient temperature, airflow details, and other heat sources in the vicinity of the damper. These influences may lead to a significant difference in the fluid temperature compared to a prediction using generic heat transfer coefficient assumptions.
The effect of the application-specific environment on the damper lifetime cannot be quantified by either the engine manufacturer or the damper manufacturer alone. Only the combination of application/ambient and damper allows for an a-priori prediction of the damper lifetime.
We present a joint, iterative CFD-based approach which enables simulation of the damper fluid temperature field taking into account the application specific ambient conditions. This combination enables a high-accuracy silicone fluid temperature prediction and thus lifetime prediction of the viscous damper. We also present a comparison of measured values with simulated results for two different applications.

Thu 13:00 Wolf-Dietrich Hall System Reliability (2B)

Motor cooling fan failures solved with modal and finite element analyses

T. Feese , J.Y. Park, D.J. Lee, Y.J. Jang
Engineering Dynamics Incorporated, Samsung Engineering Co. Ltd.

Various problems occurred on two new synchronous motor-reciprocating compressor units. Torsional testing indicated that the first torsional natural frequency (TNF) of the system was coincident with the 8th compressor order and responsible for a compressor crankshaft failure covered in reference [1]. This paper focuses on failures of the motor external cooling fan and the solution method used to improve the system. At the worst compressor load condition, torsional oscillation of the motor fan had elevated levels at 8× running speed. Modal testing of the motor fan identified a second torsional mode that could be excited by the 12th compressor order. An increase of the compressor flywheel inertia was recommended to detune the first TNF but was predicted to cause insufficient separation margin between the second TNF and the 60 Hz electrical line frequency (11× running speed). An inertia ring was sized using finite element analysis (FEA) and added to the motor external cooling fan to increase the separation margin. Follow-up torsional tests of the modified system confirmed adequate separation margins for the first and second TNFs. The speed fluctuations measured at the modified external cooling fan were significantly reduced and acceptable throughout the entire compressor load range.

Thu 13:25 Wolf-Dietrich Hall System Reliability (2B)

Torsional vibration on rotating machines in oil & gas industry and power gen industry: A review of real cases

N. Péton, J. Yu, S. Ganesh, R. Seshadri, S. Ramanathan
Bently Nevada

Lateral vibration is the most commonly measured type of vibration in machinery. However, lateral motion in the XY plane does not completely describe all the possible directions of motion of machine components. Torsional vibrations do not get the attention that they should. Since torsional vibration is more difficult to measure than lateral vibration, it is often ignored, due to an "out of sight, out of mind" attitude. In fact, torsional vibration can be quite severe and is capable of producing damaging cyclic stresses that can cause a fatigue failure. Rotating machines are all involved in the delivery or transformation of power, and power delivery requires transmission of torque. The applied torque causes the shaft to twist about its rotational axis. Thus, instead of measuring displacement relative to an equilibrium position, torsion requires measuring the angle of twist of the shaft at different axial positions. All rotating machineries undergo some fraction of degrees of torsional vibration during operations. In many cases, the torsional vibrations are not as easily identified as the translational vibrations, due to lack of simple and direct measurement devices. Typical damages developed under excessive torsional vibrations include shaft cracks, coupling cracks, gear wear, gear tooth failures, key failures, shrink fit slippage, etc. Today torsional vibration detection and monitoring becomes an important step in rotating machinery condition monitoring [3, 5, 6, 7]. Today the machinery diagnostic services team of Baker Hughes, Bently Nevada uses ADRE raw data along with self-developed Matlab executable [2, 4] application for diagnostic purposes based on phase demodulation process to the signals generated by Keyphasor® or zebra tape of tooth wheels. In this article torsional issues will be illustrated with data and pictures using 6 real cases from the industry.

Thu 13:50 Wolf-Dietrich Hall System Reliability (2B)

Grid interaction phenomena in the energy production sector

F. Petit, S. Grégoire, F. Gonzalez, F. Verbinnen
ENGIE Laborelec

This paper aims at providing an introduction to torsional vibrations with a focus on the energy production sector. Although considerable effort has been devoted to the subject leading to a profound understanding since decades, important damage to shaft lines still occurs. The main reason is that for energy production units (e.g. gas turbine power plants, wind turbines…), the excitation primarily comes from interaction with the energy grid. Consequently, changes to the electricity grid like the introduction of High Voltage Direct Current stations (HVDC) stations, heavily consuming arc furnaces, series capacitor banks … could potentially lead to excessive torsional vibrations which were not accounted for in the design stage of the unit. With the upcoming energy transition, more than ever torsional vibrations may not be overlooked. Along with some key aspects of torsional vibrations in the energy production sector including measurement results, some important known grid interaction phenomena will be outlined such as SubSynchronous Resonance, interaction with HVDC stations and heavy consuming arc furnace plants.

Thu 15:05 Karajan Hall Power System Simulation I (3A)

System approach to lower dynamic loads during resonance pass of a torsional vibration reduction system

F. Liebst, M. Geilen, P. Prystupa, S. Bindig
ZF Friedrichshafen AG, GAT – Gesellschaft für Antriebstechnik GmbH

Emission reduction (CO2, NOx, PM & NVH) in conjunction with efficiency enhancements are the main R&D drivers for today's mobile & stationary powertrains. A key element for NVH behavior (especially torsional vibrations) is the Torsional Vibration Reduction System (TVRS) downstream from the engine towards the driveline. To ensure a high level of vibration isolation during operation, the TVRS resonance speed must be kept as low as possible and thus be passed through the range during combustion engine start. Being a highly transient and random condition, this is challenging for the entire system. Significant torque peaks leading to abrupt damage or failure can be the outcome. As inducing resonance, the TVRS is the first subsystem in focus for torsional vibration optimization. Sometimes its potential isn't solely sufficient or can't be fully raised due to other components limiting overall performance. ZF performed system integration taking the entire powertrain network into account, gaining deep insight. This identified the subsystems with best leverage. A holistic approach was used primarily based on validated simulation models, experience, sensitivity analysis and a small subset of physical vehicle measurements. Troubleshooting and preventing resonance pass problems is thus accelerated. Dynamic load peaks became significantly reduced ensuring overall system durability.

Thu 15:30 Karajan Hall Power System Simulation I (3A)

Analysis and data management of torsional vibration calculation for variant and sensitivity studies

J. Wolter, P. Böhm, A. Rieß, M. Heinrich
MAN Energy Solutions SE

For dynamically loaded systems, it is well known that assessment of torsional vibrations is of great importance for a proper design of drivetrains. Classification societies require torsional vibration calculation (TVC) for the entire powertrain. This work gives insight in the high importance of an automated simulation workflow and an efficient data management. We illustrate its significant benefits in the daily work of a simulation engineer for different case studies.
One case is multivariate analysis in six dimensions with different types of flywheels, dampers, cylinder numbers, engine applications and engine maps. Different applications include for instance different power take off (PTO) requirements. The two dimensional engine map refers to different speed and load conditions with respectively different design gas pressures. The variant interaction often results in the necessity of full factorial analysis that often ends up in many thousand calculations. This high number clearly shows that manual handling of this calculation is infeasible. Furthermore, data representation in the form of compact key results is of great importance especially as a decision basis for management.
A standardized, automated and time-efficient calculation allows analysing the robustness and sensitivity of torsional systems with often more than ten thousand calculations. Here, one application is the computation of response behaviour of the torsional system regarding pressure fluctuations or the temperature determination of viscous dampers.
The article presents how all these different tasks interact and gives details to afore mentioned topics and present best-practice concepts. The outlook shows what we want to achieve in the near future like the implementation of torsional vibration calculations to a general simulation data management (SDM) that allows an overall tracking of data flows.

Thu 15:55 Karajan Hall Power System Simulation I (3A)

Creating innovative drivetrain concepts by use of agile model-based development methods
B. Juretzki
IME Aachen GmbH Institut für Maschinenelemente und Maschinengestaltung

Nowadays the use of simulation like Torsional Vibration Simulation has be-come indispensable in modern product development processes (PDP) for drivetrains in order to save cost by substituting the design validation by testing by the use of simulation. But looking at following three observations further improvements of the efficiency of PDPs are possible, especially for the concept phase of a drivetrain development:

- Usual PDPs mostly keep a linear sequence of 3D design, simulative and experimental design validation. If inadequate fulfilment of requirements is recognized in the validation phases iteration loops can jeopardize the efficiency of the process.
- In addition, current PDPs do often not integrate the data from design, simulation and testing. Thereby the need of data exchange between separated model domains is a potential lack of efficiency. Approaches from Model-based Systems Engineering (MBSE) are likely to overcome these problems.
- Furthermore, agile project management approaches, which were developed in the area of software development, offer the possibility of very short development cycles.

The IME Aachen GmbH has taken those observations into account and introduced a new concept development process which is used for internal and customer projects. Main paradigm of the process is the strict orientation on simulation models and the quantitative validation of the requirements. Concepts from MBSE and agile project management are integrated in the process.

Thu 15:05 Wolf-Dietrich Hall Measurement & Monitoring (3B)

Is what is measured the real value? Mechanical systems measurement philosophy and principles
M. Zeid
BERG Propulsion

Measurement in the industrial field is in general the way of communication with mechanical systems. The mechanical system initially requires a specific setup to function as expected. Later it performs in a certain way and another type of measurement applies to ensure that either the system keeps performing as expected (performance monitoring) or performing its designated function and interfacing properly with other functions (quality assurance in the production lines). This indicates three major domains of measurement related to a machinery system: one-time measurement, periodical measurement and continuous measurement. On the other hand, by looking into basic measuring principles at their roots, a measurement is either a quantifying measurement or a referenced measurement. Quantifying measurements used to be the most accurate and reliable way of measuring. However, it is difficult to apply where referenced measurement is the dominating principle for most of the measurement tools. This paper focuses on exploring in a simple way the layout of measurement types in different domains by considering the details of multi-referenced measurement (for example strain gauges) as well as the influence of applying different technologies for measuring the same physical parameter and digitalization influences.

Thu	15:30	Wolf-Dietrich Hall	Measurement & Monitoring (3B)

Investigation of gearbox condition monitoring using low-fidelity sensors

M. Rothemund, M. Fromberger, M. Otto, K. Stahl
FZG, TU München

Condition Monitoring of geared transmissions by measuring and evaluating acceleration signals is widely used. However, most approaches require high quality signals that lead to expensive CM systems. Less expensive measurement equipment yields coarse signals that may not be a sufficient basis to precisely recognize damages or necessary maintenance.
In this paper the authors take the approach to use a low fidelity measurement equipment combined with an adequate CM algorithm. This keeps system cost low but is intended to still allow a reasonable condition monitoring. A test system configuration is used to recognize pitting damages on gears. Results are shown and evaluated and compared to results by a high-fidelity equipment.

Thu	15:55	Wolf-Dietrich Hall	Measurement & Monitoring (3B)

Using non-contacting magnetostrictive sensors to measure torsional vibration responses in electric machinery

B. Howard, D. O'Connor, L. Turnbeaugh, C. McMillen
Bently Nevada

Torsional analysis for large machine drivetrains is an industry best practice and often required by end users. Modern computation toolsets allow for complex models; however, it is not always easy to determine the input values for the models from design data. The best models are reliant upon the correct inputs as this paper will showcase. For example, there are a variety of approaches to modelling the generator/motor field stiffness over operating conditions that give different results. Another example is determination of final variable frequency drive (VFD) tuning and filter parameters to avoid excitation of torsional resonances on the machine.
This paper develops fully coupled mechanical-electrical models for two different electrical machinery drivetrains and examines how assumptions in the modelling inputs affect the estimated torsional response. In addition, direct field measurements from non-contacting magnetostrictive sensors applied to these machines, under a variety of operating conditions, are used to assess assumptions made in the model input. Evaluation of field data includes a review of signal processing techniques for feature extraction (amplitude, phase, etc.) of torsional vibration signals. The paper concludes with recommendations for optimizing inputs to torsional models and strategies for field validation of models.

Thu 16:45 Karajan Hall Compressors (4A)

Torsional failures in hydrogen reciprocating compressor system with stepless capacity control

T. Feese, D.J. Lee , J.Y. Park
Engineering Dynamics Incorporated, Samsung Engineering Co. Ltd.

Two new hydrogen reciprocating compressor systems were equipped with stepless capacity control. Initial problems after commissioning included high crosshead guide vibration, failures of the shaft-driven mechanical oil pump (MOP) and a motor cooling fan. It was later observed by personnel at the plant that elevated vibration and speed fluctuation of the system generally occurred while operating at medium compressor load. The manufacturers performed torsional vibration analyses (TVAs) in the design stage, which predicted adequate separation margins from significant compressor harmonics. Therefore, any concerns of torsional vibration were initially dismissed. Field testing with a strain gage telemetry system found that the first torsional natural frequency (TNF) was coincident with 8× running speed. This resulted in amplifying alternating torque up to 800% of full load torque (FLT) and the system being very sensitive to compressor loading due to the torsional resonance. The compressor crankshaft and motor shaft later experienced fatigue failures and had to be replaced after a relatively short time of operation. Spiral cracks occurring at a 45-degree angle to the shaft axis were consistent with failure due to high torsional vibration. As a short-term solution, the compressor was operated at a load condition that minimized the alternating torque. The TVA was then normalized to match the field data. The long-term solution involved detuning the TNFs by adding inertia to the flywheel and to the motor external cooling fan. The modified systems were retested to verify satisfactory operation over the entire compressor load range.

Thu 17:10 Karajan Hall Compressors (4A)

Torsional damping benefits for reciprocating compressors

T. Stephens, C. Yeiser, K. Prenninger
Ariel Corporation, RBTS, Salzburg University

Engineers working with torsional vibration understand the complications that arise when designing reciprocating compressors, especially when a large speed range is desired for efficient flow control. Inherently high vibratory torque excitation, coupled with unavoidable torsional resonances often result in restricted speed ranges, exotic tuning measures, and special driveline configurations. As recently published, even moderate levels of torsional vibration can generate high levels of lateral vibration at high frequencies due to torsional/lateral coupling. Recent efforts in applying damping technology to reciprocating compressors have shown dramatic reductions of torsional and lateral vibration. When damping is applied in conjunction with the proper coupling, variable speed electric motor drive compressors can be designed to operate over a large speed range free of concerning torsional vibration. Similarly, this technology has also been successfully applied to enginedrive reciprocating compressors. Multiple case studies are provided to show impressive reductions of torsional vibration, lateral vibration, and oil pulsation with a conservative damper design. Torsional damping, when applied to large horsepower, high speed reciprocating compressors, can significantly improve reliability and flexibility as desired in today's machinery.

Thu 16:45 Wolf-Dietrich Hall Drilling and Fracturing (4B)

New insights in torsional vibrations in downhole drilling systems

V. Kulke, D. Heinisch, A. Kück, H. Reckmann, G.-P. Ostermeyer, A. Hohl
TU Braunschweig, Baker Hughes

In drilling systems torsional vibrations lead to inefficient drilling and premature failure of components. Two torsional phenomena exist that are caused by self-excitation mechanisms driven by the rock-cutting process. The first phenomenon corresponds to the fundamental torsional mode of the drilling system at frequencies below 1 Hz including excessive stick and slip phases. The second phenomenon called high-frequency torsional oscillations (HFTO) corresponds to higher order modes with frequencies between 50 Hz and 500 Hz. Dynamic effects of stick/slip and HFTO and their interaction are discussed using downhole measurement data and simulations. Analytical equations for identification and ranking of critical self-excited torsional modes and the corresponding estimation and parameter dependency of worst case amplitudes and stability are discussed. Furthermore, drilling system design options including special tools to reduce loads based on isolation and damping are evaluated. A downhole tool based on isolation is shown along with simulative, experimental and operational results. Advantages and disadvantages of isolation are compared with methods based on damping.
Different approaches are presented and methods are highlighted that could be used in other industries: The identification of critical self-excited modes, the calculation of expected limit cycle amplitudes and an estimation of the achievable damping with analytical approximations.

Thu 17:10 Wolf-Dietrich Hall Drilling and Fracturing (4B)

New approach of modeling drill bit dynamics

F. Schiefer, G.-P. Ostermeyer, M. Ichiaoui
TU Braunschweig

The dynamics of drill strings are strongly influenced by geological conditions and the cutting process in the bit-rock interface. Different models were using falling resistance characteristics with respect to the drill bit rotational speed to describe the bit-rock-interaction. The existing standard models are used to describe the influence on drill strings in the torsional direction.
The new model approach describes the influence on lateral direction especially on the generation of lateral vibrations such as whirl. This approach can be used to simulate the drilling process of inhomogeneity zones and study their influence on torsional and lateral vibrations. For the simulative analysis of the corresponding drill string dynamics, appropriate mathematical models are required, which can vary in their complexity depending on the problem. Here, a non-linear FE model, implemented in the in-house software tool OSPLAC, is used to describe drill string dynamics. Case studies of rock inhomogeneities to be drilled are simulated using the new drill bit model. The resulting vibration phenomena are manifold and are to be validated with measurement data from field tests or laboratory test stands.
The long-term goal is to provide design recommendations for improved drill string configurations and bottom hole assemblies.

Fri	09:00	Karajan Hall	Hybrid and Electric Drives (5A)

Optimizing electric drives for future demands and applications

C. Priestner, I. Garcia de Madinabeita Merino, J. Pohn, J. Garmendia, M. Mehrgou
AVL List GmbH

Current trends towards maximizing electric machine power density by package downsizing and high-speed design hold some challenges for the development of electric powertrains. Compared to conventional high torque, low speed and high weight electric drives, the system must withstand greater electric and magnetic loading. This increased loading density has several implications in the electric drive - comprising electric motor and inverter - in various domains.
Main NVH aspects to be considered when designing an electrified powertrain are torque ripple, electromagnetic forces which excite the housing, inverter induced harmonics and inverter noise radiation itself. To achieve an optimized design aside NVH also power, efficiency, thermal and durability attributes need to be considered. Such a complex optimization process can only be achieved with a multi domain approach where all the different aspects are taken into account simultaneously.
This paper shows an example of the optimization process on a real-world application and gives an outline of the potential.

Fri	09:25	Karajan Hall	Hybrid and Electric Drives (5A)

Torsional vibration calculations for hybrid drives

M. Schuchardt, P. Hinkelmanns-Stürzl
Rolls-Royce Solutions GmbH

Hybrid drives are increasingly being used not only in the automotive sector, but also for drives in the off-highway segment. The drive system, driven by a conventional reciprocating engine, is typically supplemented by an electric machine, a battery and electronic control equipment. This influences the torsional vibration behavior of the drive train in several ways. The mass moment of inertia of the electric machine, for example, has an effect on natural frequencies and resonance speeds. In addition, new operating modes arise, such as charging the battery. These must be taken into account in the torsional vibration calculation. Finally, compared to conventional mechanical drives, the reciprocating piston engine can be operated on significantly higher power curves, resulting in increased vibration excitation. This contribution demonstrates the challenges arising in the torsional vibration design of hybrid drive systems and presents concrete solutions on the basis of examples from the marine application segment.

Fri 09:50 Karajan Hall Hybrid and Electric Drives (5A)

PHEV driveline reverse engineering and torsional vibration study during engine restart and booming maneuver

T. Enault, J. Deleener
Siemens Industry Software NV

With the always more stringent regulations in term of fuel consumption, the past decades have seen many mechanical and/or control evolutions in combustion engine design. Downsizing, reduction of cylinder number, turbo charging, lower rpm torque converter lock-up strategies… all having main NVH drawbacks due to higher torsional vibration content generated by combustion engine torque irregularities. Electric powertrain is one of the answers, but the relatively low autonomy and slow charging time makes that they are preferably combined with combustion engine.
The rise of series hybrid vehicles opens the door to new NVH issue like combustion engine restart during acceleration. On the other hand, the combination of combustion engine and e-motor can be used in a smart way to reduce the torsional vibration fluctuation. This paper describes a test and system simulation-based method to study the behaviour of a Golf PHEV during engine restart and low frequency booming. The current performances are first evaluated through a detailed testing phase, then a 1D simulation model is created from reverse-engineering of the driveline. The validated model is finally used to evaluate the effect of the control and design choices towards the torsional vibration during engine restart and low frequency booming during acceleration.

Fri 10:15 Karajan Hall Hybrid and Electric Drives (5A)

VFDs – How to prevent them from destroying your torsional system

M. A. Corbo
No Bull Engineering, PLLC

In turbomachinery, electric motor-driven trains suffer far more torsional vibration problems than those driven by steam or gas turbines. The problem is compounded if the motor is driven by a variable frequency drive (VFD). In the author's experience, VFDs have been creating torsional failures at an alarming rate over the past two decades.
The paper begins with a description of VFDs, their architecture, and their different types. Of most importance, the three ways in which the presence of a VFD complicates a torsional analysis are described in detail. Particular focus is placed on the harmonic and inter-harmonic excitations that are unique to VFDs.
The paper concludes with recommended practices for machinery design engineers when dealing with VFDs. In the author's experience, these are critical, as help from VFD suppliers in this area is minimal. Accordingly, the reader is given steps to take to ensure their trains will not suffer any VFD-related field failures.

Fri	09:00	Wolf-Dietrich Hall	Powertrain Components II (5B)

Novel approach on thermo-mechanical coupled simulation and validation in rubber couplings

M. Hasan, R. Zadoks (retired)
CENTA a brand of Regal Rexnord Corp., Caterpillar Inc.

Torsional vibration analysis (TVA) is conducted to select suitable couplings for driveline applications. The heat loss value of a rubber coupling is a key result from TVA and an allowable value (limit) is needed to arrive at an optimized coupling selection. Under dynamic loading conditions, the area of the hysteresis loop corresponds to the dissipated energy which is mainly converted into heat. It is also important to capture the temperature distribution in rubber under dynamic loading, and the time dependent temperature development in rubber provides the time constant under transient loading conditions. The lifetime of rubber couplings depends on this temperature distribution which results from the dynamic loading conditions.

A multibody simulation model was used to predict the hysteresis response, and the area of hysteresis loop provided the heat loss of a coupling when subjected to vibration at a certain frequency. The temperature and heat loss distributions in the coupling were predicted using a thermo-mechanical approach. The magnitude of vibratory torque had a remarkable influence on the temperature at the core of rubber couplings. The simulation results were compared with measured experimental data obtained from static and dynamic test benches, and there was a good match between simulated and measured temperatures.

Fri	09:25	Wolf-Dietrich Hall	Powertrain Components II (5B)

Calculation of stationary temperature of rubber damper based on torsional vibration analysis of internal combustion engine

T. Parikyan, T. Kovacic, L. Jordan, M. Mulmann, S. Bonù
AVL List GmbH, AUDI AG, AGLA Power Transmission S.p.a.

Temperature calculation of torsional vibration damper (TVD) is one of the important steps in design analysis of internal combustion engine. The main targets of such calculation for a rubber TVD are:

- Assuring calculated temperatures to be below the critical level in the whole engine speed range to prevent the destruction of rubber layer;
- Evaluating the change in dynamic behaviour of the system due to variation of TVD stiffness and damping characteristics caused by increased temperature.

The paper describes a methodology and software tools to assess and to calibrate the temperature of rubber damper based on torsional vibration analysis of engine in a steady-state operation. Results of calculations of vibratory forced response of the system are compared to measurements for an automotive application example (passenger car engine).

Fri 09:50 Wolf-Dietrich Hall Rules and Regulations (5B)

Marine propulsion – Revised class rules for passing barred speed range

E. Brodin, J. O. Nøkleby, H. Amini, S. Avanesov, O. Deinboll
DNVGL-Maritime

DNVGL has launched updated rules for torsional vibrations with requirements regarding the passing of the barred speed range. This paper presents the method used to derive the time limitation requirement. It also clarifies DNVGL's approval of high tensile steel in intermediate shafts in accordance with the IACS UR-M68 Appendix-I rule.

Fri 10:15 Wolf-Dietrich Hall Rules and Regulations (5B)

CIMAC Working Group 4, Crankshaft rules – Who we are, what we do

P. Böhm, A. Rieß, T. Frondelius, J. Könnö, J. Dowell, D. Bell, Y. Hanawa
MAN Energy Solutions SE, Wärtsilä Corporation, Wabtec Corporation, Ricardo UK Ltd., Kobe Steel Ltd.

The CIMAC Working Group 4 (WG4), Crankshaft Rules, consists of about forty members from thirteen countries. This Working Group includes representatives of engine manufacturers, component suppliers, engineering companies and Classification Societies.
Our aim is to facilitate and propose updates to classification rules for the design of crankshafts aligned with state-of-the-art methodologies and to give guidance for best practice.
Besides giving technical feedback to the International Association of Classification Societies (IACS) on the Unified Requirement M53, the CIMAC WG4 currently focusses on three main topics:

- Working out a technical base for taking the cleanliness of steel into account for the fatigue strength assessment of crankshafts.
- Creating a white paper giving best practice guidance for the multi-body simulation of crankshafts. This includes recommendations for the usage of multi-body dynamics for load and stress determination in engine crankshafts.
- Working in the field of multi-axial fatigue, creating a recommendation for the multi-axial fatigue assessment for infinite life design of engine crankshafts and setting up an algorithm challenge.

Fri	11:05	Karajan Hall	Measurement and Validation (6A)

System requirements for torsional vibrations signal processing

G. Sikora, M. Dereszewski
Gdynia Maritime University

Measurements of torsional vibrations are performed in many different ways and using different techniques. No matter which technique is chosen, every measurement is based both on Big Data registration and analysis. Amount of data is mainly defined by rotational speed, encoder resolution and data type. Each second of measurement can exceed more hundreds of MB of data. Data registration with this transfer speed is possible but not efficient and not necessary. Authors of this paper propose to perform on-line data analysis, without data registration.
System concept is based on two Leine&Linde incremental encoders, mounted on opposite sides of the crankshaft, National Instruments 9401 signal board and PC. Object of this research is Sulzer AL25 diesel engine, used as an electro generator, operating with rotational speed of 750 RPM. Resolution of incremental encoders is 100 ppr. Data Acquisition System NI 9401 allows to capture single bits of data with frequency of 10 MHz. This system is assumed to be a low-cost solution for torsional vibration based diagnostics.
In this paper, above mentioned system specification is described and explained. Moreover, self-elaborated concept for on-line data analytics with its assumptions and first results are presented.

Fri	11:30	Karajan Hall	Measurement and Validation (6A)

Monitoring of transient torsional vibrations on a generator shaft in a high-power laboratory

D. Rouwenhorst, J. Hermann
IfTA Ingenieurbüro für Thermoakustik GmbH

Heavy-duty switchgear equipment is evaluated at a High-Power Laboratory, on a testbed consisting of a motor-driven shaft and a generator connected to the switchgear. Abrupt faults and switching events result in high load on the electrical and mechanical subsystems. The generator experiences the instantaneous switching of electrical loads up to nominal ratings, resulting in strong transient torsional vibrations.
For a durable operation of the generator, the strength of the torsional vibrations is to be monitored. A monitoring methodology is developed, tailored for this use-case, balancing low-noise torsional vibration amplitude determination with a high temporal resolution that is required to resolve the transient nature of the switching events.
The generator end of the shaft is fitted with a pole wheel equipped with optical measurement chains, to serve as an incremental encoder. Post-processing of the encoder signals is performed after every switching event, to obtain time traces of acceleration vibration, adjusted for lateral shaft movement and run-out pattern of the pole wheel. The measurements yield detailed time series including the first few rotational orders, which allows for an accurate estimate of the stresses induced on the generator and shaft couplings.

Fri 11:55 Karajan Hall Measurement and Validation (6A)

Rotational energy harvester for supplying self-sufficient sensor systems

M. Matthias, M. Gerhardt, M. Weber, M. Koch, T. Bartel
Fraunhofer LBF

The trend towards autonomous shipping requires the development of intelligent propulsion systems. By integrating sensors on propeller shafts, rotating components can be monitored in real time. First experimental results on a catamaran have proven the usability of dynamic data from a propeller shaft, achieved by near-to-sensor data processing and transmitting the data via Bluetooth to a receiver on deck. One challenge is the power supply of rotating sensors what causes the need for a self-sufficient sensor system, supplied by an energy harvester. Numerous concepts of rotating energy harvesters have been studied in recent years. In this paper, an energy harvester, based on the principle of an axial flux machine is developed. According to an extensive simulation of the electromechanical behaviour at a given speed range, an efficient electrical circuit for the operation of MEMS sensors, data-processing microelectronics, and wireless data transmission are developed and validated. Measurements in a powertrain test rig show that sensor data can be acquired, processed, and transmitted as soon as the drive shaft rotates at a certain threshold speed. Electrical energy can be generated both from the uniform rotary motion and from the structural dynamics of the shaft.

Fri 11:05 Wolf-Dietrich Hall Noise, Vibration, Harshness (6B)

An experimental set-up to investigate engine gear rattle problems

A. Kahraman, A. Donmez
Department of Mechanical and Aerospace Engineering, The Ohio State University

The engine gear rattle problems are caused by external torque fluctuations under lightly loaded conditions. This paper introduces a new test set-up that can simulate such loading conditions through its three-phase synchronous AC motors. The test setup has multiple modular spindles to serve as input, output, or intermediate (idler) axes of any drivetrain. Selected axes can generate user-defined torque fluctuations at the desired shapes and amplitudes. Each spindle is equipped with an absolute encoder having 20 bits resolution. Each spindle slides on a test bed, allowing a wide range of center distances as well as adjustments to the gear backlash magnitude. At the end, measurements from a single gear pair are presented, including backlash boundaries and relative displacement and velocity curves, the corresponding rattle noise levels.

Fri 11:30 Wolf-Dietrich Hall Noise, Vibration, Harshness (6B)

Overall powertrain analysis: NVH and RDE in combination

D. Höfler, S. Maxl, F. Senn, F. Burgstaller
Tectos GmbH

State-of-the-art research on Noise, Vibration and Harshness (NVH) in vehicles does not consider the impact of certain NVH events on exhaust gas emissions. In this paper, the torsional vibrations in the drivetrain and the structure-borne vibrations of a four-cylinder (inline, turbocharged gasoline engine) front-wheel drive vehicle are investigated through the comparison of Real Driving Emissions (RDE) and chassis dynamometer tests. To collect NVH and emission data, the vehicle was fitted with seven external RPM sensors to measure torsional vibrations, 15 three-dimensional acceleration sensors to measure structure-borne vibrations, five external engine temperature sensors, two additional lambda sensors to measure exhaust gas dead times, and a Portable Emission Measurement System (PEMS). To synchronize NVH data of interest and the emission data sets from these events, the exhaust gas dead times measured by the lambda sensors were utilized. The preliminary measurement results of the RDE and the chassis dynamometer tests showed noticeable NVH deviations but no significant emission differences. The data sets were then used to train different machine learning algorithms to search for correlations between the NVH and the PEMS data. Moreover, this paper introduces a data-driven speed signal correction algorithm for torsional vibration applications, which was developed using raw speed signal data from the vehicle's powertrain. Future work will focus on predicting the emission behavior of an engine in a test cell based on NVH data.

Fri 11:55 Wolf-Dietrich Hall Noise, Vibration, Harshness (6B)

Innovative solutions to reduce the transfer of structure borne noise in the powertrain of mega yachts

L. Kurtze
Vibration Association

Particularly in so called mega yachts, very soft mounted ship engines' frames are compellingly necessary to reduce to a minimum the entry of structure borne noise into the ship structure, generated by the propulsion system.
Lowest structure borne noise within the ship structure is necessary to achieve the highest comfort requirements relating to noise & vibrations. In addition, the lowest influence of any upsetting disorder generated by noise & vibrations on such a ship is required to operate the ship in its environment.
The couplings between the gearbox and the propeller shaft must minimize the transfer of structure borne noise while transmitting high torque levels. In addition, they must be resistant to high misalignments due to the very soft mounted frames of the ship engine and gearbox. Couplings also have to deal with sometimes difficult torsional vibration situations of the drivetrains. It will be shown how a lightweight coupling made of a combination of glass and carbon fibers, elastomer layers and steel is developed.
Even when keeping the noise & vibration values during the operation of the ship clearly below the specified limits, acoustic single tonal phenomena can be perceived as an upsetting and not acceptable fact. Based on the highest quality standards of the shipyards and Geislinger's strong claim to customer satisfaction, it is obvious that these effects must be analyzed in detail. To fulfill all these partly contradictory demands, innovative approaches are essential.

Fri 13:20 Karajan Hall Marine Propulsion (7A)

Torsional vibration monitoring of large container vessel propulsion train

H. Ohorn, A. Thalhammer, H. Mohr
CPO Containerschiffreederei, Geislinger GmbH, GasKraft Engineering

CPO manages and operates more than 70 container vessels including around 35 in direct ownership. The fleet consists of Panmax, Postpanmax and Super-Postpanmax types. During recent years the vessels' operation has been progressively optimized, always to regulatory and market requirements. Consequently, CPO has implemented various digitalization technologies onboard and ashore. An important part of this enhancement procedure is the detailed monitoring of the relevant systems, such as the propulsion train with the main engine.

For this specific purpose Geislinger developed a new torsional vibration monitoring system, which offers permanent monitoring of the propulsion train and integrates artificial intelligence and digital twins for anomaly detection. The system is linked to a cloud infrastructure, thus providing regular data evaluation and reporting.

CPO agreed about a respective pilot installation of the 'MSC La Spezia', a Super-Postpanmax container vessel. The installation took place during a one-day port stay in September 2021, as an update to the existing torsional vibration monitoring system. On this vessel the system monitors the torsional vibration damper of the main engine in real time and the data is available onboard and ashore via a web interface.

From the very beginning the results were very promising. This paper will give insights into the installation and respective findings such as, for example, the combined analysis of operational data and vibration measurements and the impacts on the torsional vibration analysis of a previous change to vessel's propeller to optimize the propulsion system for slow steaming. In this way the cooperation between CPO and Geislinger allows the integration of both parties' dedicated experience with ship operation and torsional vibration analysis.

In the meantime, CPO has decided to roll out the system on all nine vessels in its so-called 'Italy-class' fleet. This will result in the acquisition of broad fleet operational knowledge and prediction. Extensions of the current system scope are already under discussion.

Fri 13:45 Karajan Hall Marine Propulsion (7A)

How do the merits of iCER for engine performace affect torsional vibrations?

P. Rebholz, D. Schäpper
Winterthur Gas & Diesel Ltd., Chord X Pte. Ltd.

WinGD is rolling out Intelligent Control by Exhaust Recycling (iCER) on its large, dual-fuel 2-stroke marine engines to further enhance their performance, to meet IMO Tier III emission regulations in diesel and in gas mode without additional aftertreatment, and to reduce methane slip. This paper discusses the effects of the iCER technology on the combustion, the resulting reductions in fuel consumption, and the implications on typical directly coupled X-DF engine installations like LNG carriers and modern container vessels. The results show a high sensitivity to the type of installation: While torsional vibrations can be reduced with the lowTV tuning for lower cylinder numbers (5-7), the change in tangential excitations must be considered in the dimensioning of torsional vibration countermeasures for higher cylinder numbers (8-12).

Fri 14:10 Karajan Hall Marine Propulsion (7A)

Marine propulsion shafting excessive torsional vibrations: Case studies

B. Cowper, Z. Schramm
LamaLo USA, LLP

Theoretical torsional vibration analysis of marine propulsion shafting systems has been shown to provide good results and assurances that the shafting design and operations can avoid excessive vibrations. Systems with low-speed diesel prime movers are well known for their barred speed ranges due to resonant torsional vibrations. Measurements are taken during sea trials to verify the barred ranges. However, for other systems which incorporate gearing, flexible couplings, cardan shafts, higher shaft speeds, and other non-conventional components, the torsional vibration characteristics can be difficult to estimate. Yet the torsional vibrations are not always measured during sea trials. Unfortunately, costly failures can occur. Direct measurement of the torsional vibratory stresses with near real-time display have proven to be reliable in identifying excessive vibrations and remedial actions to be taken. This paper provides examples of cases where excessive torsional vibrations were measured. The measurement technique, results and actions taken to prevent further failures are likewise presented.

Fri 14:35 Karajan Hall Marine Propulsion (7A)

Effect of heavy flywheel for torsional vibration on shaft alignment

T. Mitsukiyo
Mitsui E&S Machinery Co. Ltd.

Recently, torsional vibrations have become more severe on vessels installed with 2-stroke low-speed diesel engines and direct-coupled propulsion shaft-lines. The background is the current trend in diesel engine design towards longer strokes, higher cylinder pressures, lower engine revolutions and derating of engine power in order to meet the demands of environmental regulations and to improve fuel consumption. There is also a trend to heavier flywheels since additional flywheel mass is well known as one of the simplest and most effective measures for torsional vibrations, reducing the stress and shifting the resonance RPM. From the viewpoint of shaft alignment, the bending moment of the crankshaft is increased by the heavier flywheel. This is an important matter for crankshaft deflection and shaft alignment, which is usually planned and calculated by the shipyard. This paper shows that in terms of torsional vibrations a heavy flywheel has a significant influence on shaft alignment.

Fri 13:20 Wolf-Dietrich Hall Power System Simulation II (7B)

Comprehensive torsional simulation of generator sets – Part I: Calculation of torsional maps

B. Mokdad, C. Henninger, J. Keske
Liebherr Components Colmar SAS, Liebherr Machines Bulle SA, Kohler Co.

Torsional vibration calculations provide a good overview on the vibrational behavior of specific generator set configurations, and allow for evaluation against relevant criteria on the engine and alternator rotor components, such as torsional stresses and accelerations, or torsional damper power loss. To allow for rapid assessment of generator set torsional dynamics, Liebherr provides so-called torsional vibration maps for its engines. In these maps, the relevant assessment criteria are plotted in dependence of alternator rotor inertia and shaft stiffness. These results can be used to quickly assess the torsional dynamics of a specific alternator rotor for the engine under consideration. Furthermore, the maps enable the customer to identify the alternator rotor torsional parameters to achieve an advantageous torsional behavior of the generator set.
In this contribution, the calculation of torsional maps from generalized torsional dynamic calculation is presented for a V-type 12-cylinder diesel engine for power generation applications. The impact of the alternator rotor modeling approach on the crankshaft torsional stress, the torsional vibration damper power loss, and the alternator rotor shaft stress and acceleration amplitudes is detailed. An example is highlighted demonstrating how the generalized simulation approach drove design improvement of a specific alternator rotor.

Fri 13:45 Wolf-Dietrich Hall Power System Simulation II (7B)

Comprehensive torsional simulation of generator sets – Part II: Capturing armature core twist of alternator rotor assemblies in torsional models

J. Keske, B. Mokdad, C. Henninger
Kohler Co., Liebherr Components Colmar SAS, Liebherr Machines Bulle SA

Construction techniques for the rotors of alternators and motors exhibit physical characteristics that do not lend themselves to accurate torsional modeling via analytical calculation or the finite element method. While the total inertia of a rotor assembly can be accounted for and distributed appropriately in a model, the effective stiffness of the rotor in its assembled state is difficult to calculate due to the complex nature of the interactions between laminations, copper wire windings, varnish, and other structural components. The B.I.C.E.R.A. Handbook on Torsional Vibration provides an analytical method for shaft stiffness calculation involving shafts fortified with armature cores. However, the accuracy limitation of this method has been realized.
In this paper, a method to determine effective shaft stiffness values as part of a multiple degree of freedom (DOF) torsional model to characterize the entire rotor assembly is presented. The method utilizes selective processing of experimentally measured modal parameters to solve for the system model stiffnesses.
A case study is presented comparing a 3DOF model of an alternator rotor assembly, derived using the B.I.C.E.R.A. method, to a 9DOF model that captures armature core twist. In the study, the rotor is coupled to a diesel engine in a generator set application. A comprehensive torsional simulation including combustion excitation is compiled as described in the companion paper. Simulation predicted responses are compared to running measurements. The 9DOF model is shown to be significantly more accurate than the 3DOF model.

Fri 14:10 Wolf-Dietrich Hall Power System Simulation II (7B)

Torsional elasticity of flange contact using finite element method

S. Virta
Winterthur Gas & Diesel Ltd.

It is essential to accurately characterize the torsional vibration system of a direct coupled 2-stroke marine engine. The shafting is a multipiece structure with different shaft connections that together form a complex vibrational system, which is commonly simulated in one dimension. It is therefore necessary to simplify the model by replacing some components by equivalent pieces of straight shaft of the same torsional elasticity. In flanged couplings this means that details like holes for the bolts and small nonlinearities in the flange contact are usually neglected and an equivalent best fit diameter is selected for the calculation.
This study aims to define an equivalent diameter of a flange with respect to the dimensions of the shaft coupling. To achieve this, finite element method is used. In addition, the same approach is applied to determine the influence of a longitudinal slot to the elasticity of a shaft.

Fri 14:35 Wolf-Dietrich Hall Power System Simulation II (7B)

Illustrating the benefits of a torsional vibration damper for eliminating the barred speed range by using hybrid finite element modelling methods

C. Leontopoulos, O. Vlachos, K. Prenninger, A. Thalhammer
ABS, Salzburg University, Geislinger GmbH

Due to the efficiency and emission goals imposed on modern vessels, acceleration through the barred speed range can be challenging. Since the Main Engines' MCR tends to be set at a low RPM, the position of the Barred Speed Range is pushed to lower RPM and power settings. However, by making the full range of speed settings available to the ship operators, manoeuvrability increases for vessels that frequently go in and out of port due to their operational profile. This also reduces the overall emissions. In this study, the propulsion shafting system of a typical modern container vessel is reviewed, focusing on its torsional vibration characteristics. The system is modelled in a commercially available finite element analysis (FEA) software package, using hybrid modelling as a mixture of 2D pipe elements, matrix elements and a 3D crankshaft model by using superelements. All six (6) degrees of freedom and their couplings, such as torsio-axial and torsio-lateral are considered, and the modelling techniques explained. A commercially available torsional vibration damper is then used to eliminate the imposed barred speed range of the system, and the analysis is repeated to verify the results under the same assumptions. The final analysis is followed by a brief technical/economic discussion evaluating and assessing the overall cost-benefits of the installation.

Fri 15:25 Karajan Hall Digital Twin (8)

Digital twin of induction motors for response analysis of electric drive trains

T. P. Holopainen, T. Ryyppö
ABB Motors and Generators

Torsional vibrations must be considered in the design of all high-power drivetrain systems including an induction motor. Magnetic fields in the air gap of induction motor generate additional stiffness and damping between the rotor and stator. However, the inclusion of these magnetic effects is limited by the availability of portable motor models. The aim of this paper is to introduce a portable digital twin of induction motors for torsional analyses of drive trains. This digital twin is based on the common equivalent circuit model of an induction motor. However, the parameters of this model are identified by a specific finite element analysis. The mechanical drive train is modelled with a compatible system of first-order differential equations. The calculation example is a motor-driven reciprocating compressor. First, the magnetic effects are demonstrated by comparing the natural frequencies and damping factors with a linearized model in the operating point. Next, the reclosure analysis results are compared to the fully coupled finite element simulations. The obtained results demonstrate the complicated nature of the transient reclosure analysis.

Fri 15:50 Karajan Hall Digital Twin (8)

Application of digital twin technology on torsional vibration systems

C. Pestelli, F. Degano, P. Sundström, M. Almerigogna
Wärtsilä Corporation

Safe ship operations around the globe are secured through the successful design and validation of the vessels power train. The most important design load considered is the stress induced by the torsional vibration and many resources are spent every year to build, maintain and update the numerical models. After the design phase those models are stored in a database and very seldom used again thus not producing any additional value for the company anymore. Wärtsilä believes that this can be changed with the application of a new emerging technology: the Digital Twin.
The idea is simple: considering that the Digital Twin is a digital replica of a physical assets, the torsional vibration models can be considered the Digital Twins of the corresponding power trains of the sailing ships if the simulations are running in parallel together with the asset in operation. Nowadays the engines are equipped with many different sensors for automation and control purposes; so if a torsional vibration model is fed with the input signals of a running engine, then it can be used to represent a real engine in operation in real time and a Digital Twin is thus created for that specific application.
The Digital Twin technology application opens many different scenarios, from the engine monitoring, the condition-based maintenance (CBM), to the predictive and proactive maintenance. In practice, with the Digital Twin technology Wärtsilä can bring in the field, close to the customers, the expertise of the engineering department and a new set of functionalities, allowing safer engine operation and a better maintenance planning with the corresponding economical benefits for the ship owners.

Fri 16:15 Karajan Hall Closing session (9)

New opportunities of big data analytics for torsional vibration analysis

A. Thalhammer
Geislinger GmbH

During the last decades, there have been several approaches established to continuously monitor and measure torsional vibrations (TV) in a powertrain. The goal of these condition monitoring installations is to detect abnormal behaviours and resulting overloads - typically based on data that cover a rather short time horizon. Additionally, the available dataset is limited to a pre-defined number of installed and available sensor signals.
However, torsional vibrations are highly correlated to a large variety of the system's boundary conditions that are typically not entirely covered and recognized by the standard monitoring installations. Hence - for efficiently link measurement outcomes to simulation results - additional context information and sensor signals are required.
An adaption of the whole measurement scenario onsite is generally a very time-consuming task and therefore, such upgrades to obtain extended information about the state of the powertrain are often avoided due to time and cost constraints. In addition, the requirements for monitoring systems are constantly increasing nowadays - especially if operator and stakeholder expectations include predictive analyses to improve efficiency and performance of the powertrain and to enlarge or omit service intervals of drivetrain components.
In this paper it is illustrated how the frontiers of the locally installed vibration monitoring can be overcome by setting up a big data infrastructure and communication between various onsite- and backend systems. With such a big data approach it is possible to connect historical measurement data to enhanced analytical models including required context information from external resources. More specifically, the focus lies on investigating how analytical models for prediction and anomaly detection are derived for continuous measurement data and how these analytics together with context information can be utilized to enrich simulation models for the torsional vibration analysis.

Map – City of Salzburg

1 Hotel Sheraton Grand Salzburg
2 Star Inn Hotel Salzburg Gablerbräu
3 Motel One Salzburg Mirabell
4 Hotel am Mirabellplatz
5 Hotel Imlauer Pitter Salzburg
6 Hotel Europa Salzburg

A Salzburg Congress
B Welcome Reception, Restaurant M32
C Gala Dinner, Residenz

Symposium Location

The Salzburg Congress is within walking distance of the historical city centre and most hotels, and can be easily reached by bus. It is also located right next to the famous Mirabell Gardens. The Symposium will be held on the first floor of the Salzburg Congress, in the Karajan Hall and the Wolf-Dietrich Hall.

Salzburg Congress
Auerspergstraße 6
5020 Salzburg / Austria

Symposium location: Salzburg Congress

TORSIONAL VIBRATION SYMPOSIUM

Salzburg Congress floor plan

Entrance

Exhibitors

AVL List GmbH (2a)
Bently Nevada (9)
CENTA a brand of Regal Rexnord Corp. (6)
core sensing GmbH (15)
Dewesoft GmbH (2b)
Engie Laborelec (5)
Geislinger GmbH (1)
Hasse & Wrede (8)
IBIS GmbH / Laschet Consulting GmbH (12)
IfTA GmbH (17)
Intellectual Maritime Technologies (11)
Lo-Rez Vibration Control Ltd. (16)
Optel Thevon (4)
OROS (10)
Telemetrie Elektronik GmbH (14)
Vispiron Rotec (3)

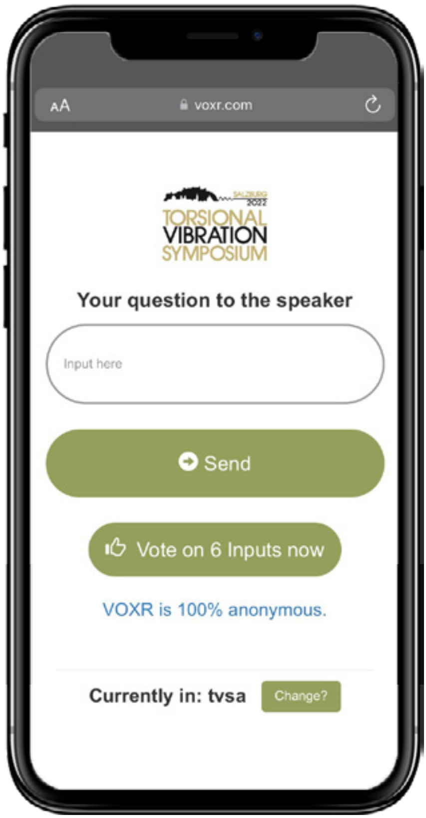
VOXR

During the conference, the VOXR online questionnaire tool will be used to record and ask questions regarding the presentations.

You can access the VOXR tool via any browser on your mobile phone. In order to start, please type one of following links in your browser bar or scan the appropriate QR code.

In the **A-Sessions** (Karajan Hall), please use:

www.voxr.com/tvsa



In the **B-Sessions** (Wolf-Dietrich Hall), please use:

www.voxr.com/tvsb

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APPLICATION ENGINEERING

Regardless of whether you have a first draft or very particular ideas, whether a standardized solution or a completely new concept is to be developed: Your task is the focus of our advice. We will be happy to support you with our inventiveness and experience and work with you to find the right solution for your application.
Let's talk about it.

TEST ENGINEERING

Our designs are subject to extensive torsional vibration analysis, multi-mass and finite element analyses. Several test beds, each of them for different tasks and performance ranges, cover the practical side of our program. CENTA offers a reliable malfunction analysis of your plant and a practical verification of the theoretical calculation results as part of the product development process. Close contact to external research facilities ensure nothing is left to chance.

Welcome Reception

Welcome Reception*, Restaurant "M32"
Wednesday, May 11, 2022, 18:00

Please use the elevator called "Mönchsberg Aufzug" to reach the restaurant on top of the city hill Mönchsberg. Our staff will welcome you there and show you the way up to the restaurant M32.

Address: Mönchsbergaufzug, Gstättengasse 13, 5020 Salzburg

Restaurant M32

Old town of Salzburg

The M32 is located on one of the city hills of Salzburg. Matteo Thun's design combines naked concrete and vivid colors, and is dominated by the 390 stag antlers adorning its walls. Due to the restaurant's top location, the entire city can be admired from the dinner table while enjoying traditional Austrian or simple Mediterranean cuisine. The M32 offers a modern and creative, yet delightful and natural atmosphere combined with a stunning view and excellent food.

*The "Welcome Reception" is included in the Symposium Participation Fee. The tickets for the elevator to the Mönchsberg will be available at its entrance.

Gala Dinner

Gala Dinner*, Salzburg Residence Palace
Thursday, May 12, 2022

18:30 Aperitif
19:30 Gala Dinner

Address: Residenzplatz 1, 5020 Salzburg

Residence Palace

The old residence palace is the Prince Archbishop's palace complex. It is surrounded by the cathedral square (Domplatz), the residence square (Residenzplatz) and the Sigmund-Haffner alley, which spans from our city hall to the Franciscan church (one of the oldest churches in Salzburg). It was first built in 1120, but completely demolished and rebuilt in 1597 in the style of the late renaissance on the order of Archbishop Wolf Dietrich. In the residence, there is a total of 180 rooms, containing 15 pompous baroque rooms, which never fail to fascinate and impress visitors.

*The "Gala Dinner" is included in the Symposium Participation Fee.

Social and Cultural Program

Kehlsteinhaus (Eagle's Nest)
Saturday, May 14, 2022
Participation Rate*: EUR 50,- / Person, Registration required

The Kehlsteinhaus (Eagle's Nest) on the Obersalzberg Mountain in Berchtesgaden is located at a height of 1820m above sea level and is a popular day-trip destination. Originally built by the Nazi Party as a symbol of power, decisions were made at the Eagle's Nest. The building stands perched over a sheer rock wall and a road was cut into the mountain through previously impassable terrain. Although most of the monuments from this era were damaged during World War 2, allied bombing did not damage the Eagle's Nest.

Kehlsteinhaus (Eagle's Nest)

Today the Eagle's Nest remains in its original state and still offers a magnificent and unique view of the surrounding countryside.

*The "Social and Cultural Program" is not included in the Symposium Participation Fee.

Alternative Program

Should it be rainy or foggy, we offer an alternative museum program:
Participation Rate*: EUR 50,- / Person, Registration required

Haus der Natur (House of Nature)

With more than 7.000 m², Salzburg's most popular museum presents fascinating nature: from beautiful underwater worlds in the aquarium to extra-terrestrial experiences in the outer space hall, from colossal dinosaurs from a bygone age to a journey into the human body. Another highlight: hands-on experiments in Austria's most comprehensive science centre. We offer a special guided tour through the impressive exhibitions.

Haus der Natur

Domquartier

Domquartier

The "Residenz" is not only the location of our gala dinner but also offers fascinating architecture and history. Fantastic paintings in the "Residenzgalerie", a fabulous view into the Cathedral, the sacred treasures of the Cathedral Museum and revolving special exhibitions in the Northern Oratory await you. At the new Museum of St. Peter's Abbey you will see the precious objects of the Benedictine monastery's art collection. Fascinating details about the history and architecture complete this tour.

*The museum tickets are not included in the Symposium Participation Fee.

General Information

Oral Presentations

All oral presentations are scheduled as follows:

- 20 minutes lecture
- 3 minutes discussion
- 2 minutes break (possibility to change rooms)

This schedule should be strictly observed. It is not possible to exceed 20 minutes for a presentation. In each room, a laptop, a beamer, and an audio loudspeaker are available. The laptops are equipped with actual Windows, MS-Office and Acrobat Reader. Please store your presentation on a CD-ROM or a USB flash drive, bring it to the conference and make sure to transfer it to the laptop of your technical room well before your session starts. It is not allowed to use personal laptop computers for presentations. Please perform a virus check on your data storage device. For PowerPoint presentations, we recommend to create an additional file, which is system-independent. Please choose "pack and go" in the file menu. Since we don't assure the compatibility of your presentation with the installed power point version, a preview corner will be available to check your slides during the conference.

Photography and Video Recording

Photography and video recording of any lecture or poster are not permitted.

Congress proceedings

The papers of all sessions will be available on the USB-Stick in the conference bag.

Contact

The Organizer of the event is the Vibration Association.

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(Vibration Association)
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