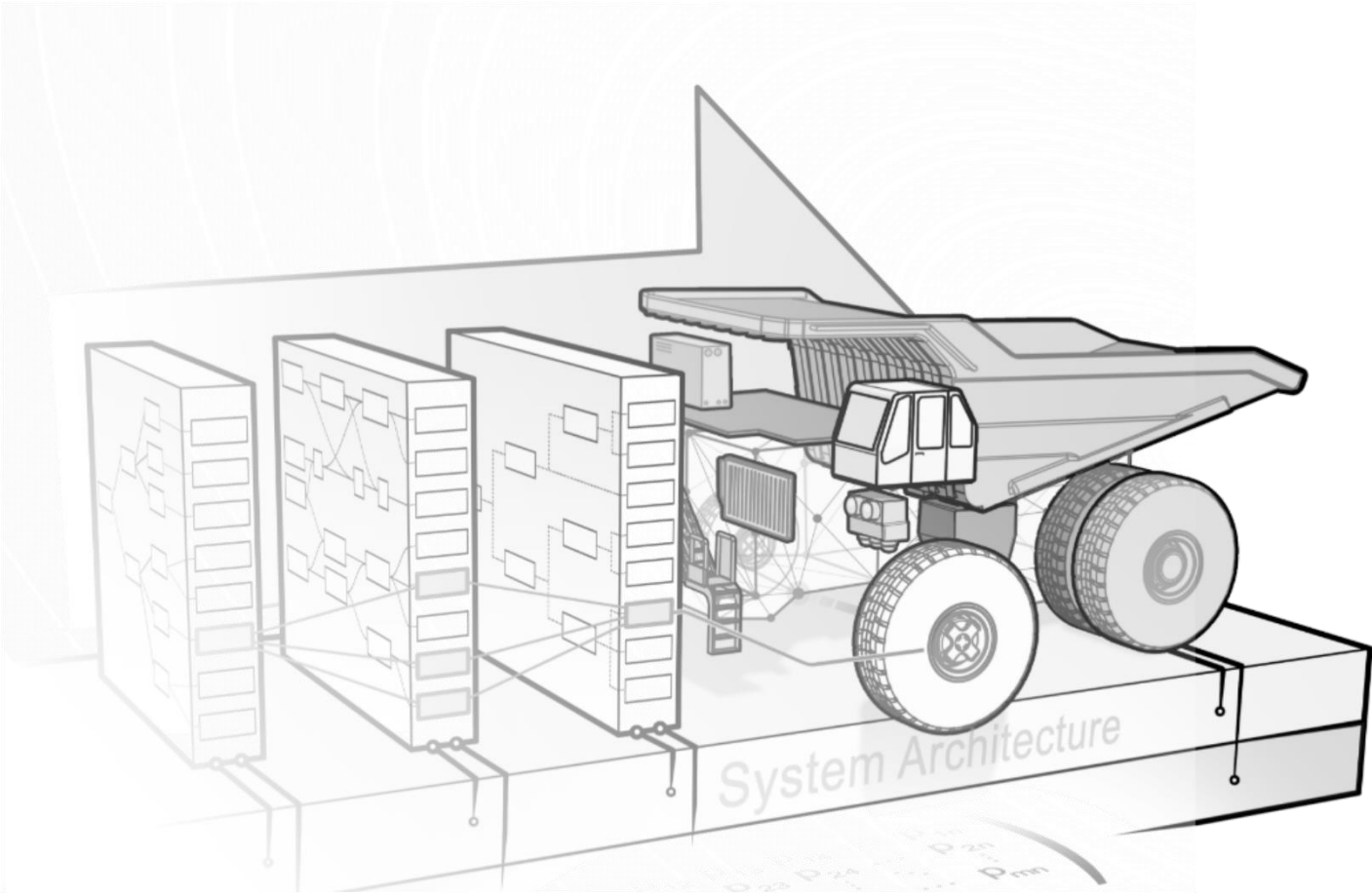
DSEC 2023 DRIVETRAIN AND SYSTEMS ENGINEERING CONFERENCE

Eurogress, Aachen March 21 - 22, 2023



BOOK OF ABSTRACTS

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Machine Elements: Bearings, Sealings, Gears, Couplings

Sustainable Gearbox Dimensioning Based on Real Loads

Marc Lehmkuhl

Flender GmbH

Abstract: Modern computer calculations allow effective and accurate designs of gearbox components. Common ways to get load cases for these calculations are less accurate. Presumed loads are often based on past damages, low dynamic motor current measurements or experiences of the past. To compensate the missing knowledge, higher safety factors are typically selected. This conservative way of dimensioning entails the risk for oversizing.

A few years ago, there was only a low transparency of real loads and dynamics in the industry. A low count of damages together with expensive measurement projects indicates the general tendency for oversizing. In 2017, a low-cost measurement system for gearboxes was developed by Flender. Cost-effective speed and torque sensors as well as a smart data logger form the basis for this system. The development enabled the measurement of load data in a huge amount. Many different industry applications could be observed up to now.

The paper shows the project status. Measurement results of selected applications and their consequences are discussed. An overall view of the present results is giving an idea on how many tons of steel, energy and other resources can be saved by focusing on real loads during design processes. This process is based on the fit for purpose approach. The reader can see how this approach will be pushed to a new level and how a sustainable and modern standard in drive train dimensioning will be enforced by Flender.

Development of a High-Precision Radial Plain Bearing to Improve the Efficiency of external Gear Pumps

Lars Brinkmann

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Abstract: Emerging electrification trends in mobile hydraulics increase the demand for highly efficient external gear pumps. Regarding volumetric efficiency, the radial bearing clearance is one of the most important geometric parameters of these pumps. It influences the positioning of the gear shafts and therefore possible misalignments of the gears like axial tilt. These misalignments in turn change important sealing gaps, for example in the tooth contact, and consequently affect the volumetric efficiency. For this reason, the radial bearing clearance must be adjusted accurately with low tolerance. To achieve this, there are various technologies available to reduce the inner diameter tolerance of the assembled plain bearing sleeves (i.e., plain bearing materials and methods for tolerance reduction like calibration or machining). This contribution focuses on the evaluation of these technologies with respect to achievable tolerances and manufacturability.

Parametric System Simulation of Load Sharing in Planetary Gearboxes

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Abstract: Load sharing and contact pressure distribution is of high priority in the design of planetary gearboxes to ensure high torque density at lowest possible cost. Unfortunately, detailed experimental results are only available after prototype testing, which is usually too late to make fundamental changes in the gearbox design. Simulations to predict the load sharing on the other hand are also only possible after the gearbox has reached a certain design status. Current standards and guidelines for gear and gearbox design like AGMA, IEC or ISO only give very unspecific advice how to choose the load sharing factor, effects of the system stiffness or the actual tolerances of the gears and structural components are not considered and the stated values for the load sharing factor is often quite conservative. This leaves the gearbox designers with a lot of uncertainty when a new gearbox is developed, leading to lower torque densities than possible.

To solve the mentioned issues a parametric FE-model was developed, including the gears with the modifications, all relevant structural components as well as simplified bearing models. It allows to build complete gearbox systems and for wind turbine gearboxes even the implementation of surrounding structures like the main shaft or the main bearing. The model only relies on the gear data, which is usually available in the early phases of a gearbox development, and a few assumptions regarding the geometry of the structural components. All contacts, solver settings and boundary conditions are automized to allow parameter studies for optimization.

In the presentation the structure of the model is explained and the results of some example simulations regarding the effect of gearbox size, number of planets and machining tolerances are discussed to show the capabilities of the tool. A comparison between the simulations and current guidelines is also given in the presentation.

Machine Elements: Machine Elements: Wear, Fatigue and Friction

Prediction of film thickness for starved elasto-hydrodynamically lubricated rolling contacts using CFD method

Shuo Zhang

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Abstract: Nowadays, more than 90%of all rolling element bearings are grease lubricated. Grease releases oil to separate the contacting surfaces by forming a stable oil film, thus resulting a long service life of a bearing. The film thickness is usually calculated by assuming fully flooded conditions. However, if the amount of released oil is insufficient, the film thickness will be reduced, which is termed as starvation. Grease lubricated rolling bearings have the risk of starvation even at fairly moderate speeds, which implies a high risk of wear and bearing failure. To reduce this risk, an accurate starvation model to predict film thickness under starvation is needed. In this contribution, a new starvation model based on the CFD method is used. The effects of starvation on film thickness and surface deformation are analyzed. For starved condition, film thickness at contact sides still remains fully flooded but decreases around contact center line because of the spring-back resilience of the material. Meanwhile, with increasing speed, the maximum deformation increases.

Bio-based polymeric thickener systems for bio-based lubricating greases

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Abstract: Grease, a lubricant typically used in rolling bearings, is made up of base oil, thickener, and minor amounts of additives. Petrochemical base oils and thickeners are primarily used in the manufacture of commercial greases. Recently, the lubricant industry has put a lot of effort into developing base oils made from renewable resources. However, the thickener must also be made from renewable resources in order to create a totally bio-based grease. The design and assessment of three distinct bio-based polymer thickener systems are thus presented in this paper. To describe the lubricating characteristics of newly created bio-based greases, tribological tests are carried out. The results indicate promising potential of bio-based greases to be considered as an alternative for petrochemical greases in rolling element bearing applications.

Pitting Load Carrying Capacity of Additively Manufactured Spur Gears Made by PBF-LB/M of Case-Hardened Steel

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Abstract: Reducing the mass in future powertrains is a key factor for reducing the energy consumption as well as for limiting CO2 emissions. Mass reduction can be achieved by lightweight structures, for example. Additive manufacturing technologies are ideal for the implementation of lightweight structures because of the high freedom in design. Additively manufactured gears with lightweight structures could be used in future powertrains to reduce mass. However, this requires fundamental knowledge about the pitting load carrying capacity and tooth root bending strength of additively manufactured gears for an adequate gear design according to ISO 6336. Neither aspect has been sufficiently quantified by research so far.

The present study focuses on the pitting load carrying capacity of additively manufactured cylindrical gears with different lightweight structures made by laser based powder bed fusion (PBF LB/M, ISO/ASTM 52900) of 16MnCr5 and 20MnCr5 steel powder. With the additive manufacturing technology of PBF LB/M, a part is created layerwise by melting and solidification of metallic powder particles with the energy of a laser beam. The examination of the pitting load carrying capacity was conducted on an FZG back to back gear test rig. Further investigations considered various material characteristics. The additively manufactured gears with a mass reduction up to 45 % have a pitting load carrying capacity comparable to conventionally manufactured gears (wrought and machined).

Environmentally acceptable ester-based lubricants - Evaluation of lubricants with respect to the operational requirements of marine propulsion systems

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Abstract: Lubricants for stern tube systems are subject to increasingly stringent requirements in terms of environmental compatibility, as any lubricant leakage leads to contamination of the sea. As a result, interest in environmentally acceptable lubricants (EALs) is increasing. Biodegradable ester lubricants represent a possible alternative to conventional, mineral oil-based lubricants. In addition to environmental compatibility requirements, these ester lubricants must also meet tribological requirements. In this study, suitable tribometers were therefore combined in a pre-screening method to cost-effectively test lubricants for their tribological requirements (friction efficiency, wear protection and scuffing capacity). For this purpose, the contact parameters are transferred from the real conditions in the stern tube system's journal bearing and from the standardized component tests (FZG for gears and FE8 for rolling bearings) to tribological model tests on a Mini-Traction-Machine (MTM, PCS Instruments). The result of the study is a method for the pre-screening of EALs under the application-related journal bearing and standardized component test conditions, respectively. The results show an influence of the lubricant composition on the friction efficiency in fluid friction as well as the transition point from fluid to mixed friction. Furthermore, an influence of the lubricant composition on the scuffing capacity could be shown. The results of friction efficiency and scuffing capacity confirm also a high reproducibility for those pre-screening tests.

Machine Elements: Digitalization and Sensor Integration

Extension of the system boundary of the Digital Twin onto the sensors of the Physical Twin through the introduction of redundant soft sensors

Michel Fett

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Abstract: The benefit of digital twins depends to a large extent on the quality of the sensor data provided. Sensor failures are sometimes only detected late in operation and can have serious consequences. For this reason, one approach is to use redundant sensor systems that monitor each other. However, due to the additional sensors required, this is associated with additional financial and design effort.

In this publication an alternative is presented, which provides a redundant sensor system with the help of soft sensors. Soft sensors use physical sensors that are already installed to anticipate a new measured variable via algorithms. They are often used to avoid placing sensors in hard-to-reach locations, but are used here to perform redundant computation of already existing metrics. The sensor data of physical and soft sensors are used as input variables for a digital twin. Here, these are compared with each other and can be critically questioned by the twin itself. This makes it possible to extend the system boundary of the digital twin to the sensors themselves. Provided input variables are no longer assumed to be set. This allows sensor failures to be detected at an early stage and consequential damage to be averted.

Sensor integrating plain bearings: Design of an energy-autonomous, temperature-based condition monitoring system

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Abstract: Plain bearings are increasingly being used under mixed friction, resulting in a higher risk of wear-induced failure. Therefore, the relevance of condition monitoring is increasing, which can enable the early detection of wear inducing conditions. The presented work focuses on the development of an energy-autonomous, temperature-based condition monitoring system for plain bearings. The components of the condition monitoring system are to be integrated directly into the machine element and operating data to be transmitted wirelessly.

The fundamental monitoring approach pursued, is the in-operando calculation of the lubrication gap height via the standardized Gümbel-curve based on the temperature map in the plain bearing. If the gap height undercuts a critical threshold, the plain bearing will operate in mixed friction. Thus, representing a potentially wear-causing operating point. The energy required for operating the system is harvested thermoelectrically within the plain bearing via thermo-generators, which use the temperature gradients in the plain bearing during operation.

In this work, the simulative evaluation of the harvestable energy will be presented. The usable temperature difference will be determined for varying positioning of the energy harvester. The results obtained allow the subsequent manufacture of a first Sensor integrating Machine Element (SiME)-prototype. In this context a feasible setup regarding the types and number of sensors as well as a microcontroller for processing the measured data will be defined with respect to the harvestable energy. Furthermore, the principle for temperature-based gap height determination will be introduced, applied for different operating points and compared to simulative results.

Systematic identification of disturbance factors on electric characteristics of gearboxes

Maximilian Hausmann

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Abstract: Machine element failures can cause critical machine breakdowns, e.g. bearing damages nearly 20 % of all machine failures. So monitoring machine elements is of particular importance for condition monitoring of gearboxes. Therefore, new approaches based on electrical impedance analysis are proposed in literature, e.g. for the measurement of rolling bearing load or damage condition with so-called sensory utilizable machine elements (SuME). For this approach, an electric signal is transmitted through the structure to be observed and the resulting impedance is measured. With this technique, it is possible to detect loads and damages not only for bearings, but also for the whole gearbox. Another application of this method can also be the transmission of electric signals through machine elements and the gearbox themselves. However, uncertainty arises with regard to the distinct signal transmission in these processes, mainly caused by parasitic currents. In this contribution, the parasitic influences of a gearbox at different working points are investigated. For this purpose, potential disturbance factors are systematically identified and then used as basis for a full factorial experimental design for screening the operational characteristics of the gearbox. The data obtained from the tests is subsequently analyzed to identify correlations between the disturbance factors and parasitic influences. In case of a support by hybrid rolling bearings, a dependence of the electrical capacitance of the gearbox on temperature and revolution speed is shown, while radial and axial loads as well as torque have no significant influence. By using regular bearings with steel rolling elements instead of hybrid bearings, an additional load dependence can be observed. This is caused by the electric behavior of rolling bearings under load. These results can be used for further development of SuME as well as evaluation of related measurement data by reducing the associated uncertainty.

Intelligent, wireless and highly adapted. The potential of Integrated Sensing technology demonstrated on a tooling machine spindle

Lois Jacob, i4M technologies

Henning Buhl , IFW of Leibniz University Hannover

Abstract: For condition monitoring and predictive maintenance of a wide variety of structural systems and machine components, a lot of condition data and information is needed. This data is still often collected manually at regular time intervals, which requires a lot of human resources and system downtime. Therefore, enabling online data collection and condition monitoring of a system is a widespread request. However, the challenge is that sensor technology and associated data processing usually have to be retrofitted into the existing system or machine component. Additionally, the functionality of the system must not be restricted in the process.

Moreover, the challenge is usually the depth of integration into the existing system and the available installation space. In this paper, an intelligent wireless sensor system is presented, which was integrated into a machine tool using the example of a grinding spindle with a high integration depth and an installation space requirement smaller than a 1 euro coin. By means of the integrated sensor module, four external strain gauges based on semiconductor technology are used to measure the static load collective on the shaft of a grinding spindle. In addition, the acceleration and rotation data of a 6-DoF IMU is captured in order to detect the dynamic movements of the shaft. The measurement data is made available to the control of the machine tool by means of contactless data transmission.

In the example presented, the structurally integrated, contactless sensor system enables process force measurement during a grinding process. Based on the measured forces, an online adaptation of the path control of the machine tool can be implemented, so that the setup effort and the production scrap of the machine are reduced and condition monitoring is enabled.

Systems Engineering: Processes, Methods and Tools I

Successful Planning, Deployment and Application of MBSE

Sven Kleiner

:em engineerings methods AG

Abstract: Component and system development are focusing on implementation of functions in the field of autonomous capabilities, connectivity, electrification and digitalization today. However, manufacturers and their suppliers still handle and process simple text-based specifications and 2D drawings in order to deliver complex products. Hence, Requirements Engineering and Model-based Systems Engineering (MBSE) are key in order to meet the requirements towards quality, time and cost for the development of mechatronic products and cyber-physical systems. The Model-based Systems Engineering approach can help to move from a document-centric approach to a model-based development methodology based on Requirements Engineering, System Modeling for System Architecture Design and Simulation in early design stages.

This talk presents challenges and experiences from industry during the introduction of MBSE and outlines an approved way how to deploy MBSE successfully based on the “MBSE-Roadmap in 20 days” approach.

References and examples from industry will showcase a new way of working and how product development can be enhanced by adopting MBSE. In addition, best practices best on organization, processes, methods and tools for MBSE and their application (e.g. CAMEO, CATIA Systems and 3DExperience) will be outlined.

Last but not least an outlook towards Advanced Systems Engineering – the future of (Model-based) Systems Engineering - will be given.

Customer-Centric and Function-Oriented Development of Mechatronic Systems

Laura Brand

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Abstract: Successful products at least precisely meet the customers' expectations and, in the best case, surprise them. To develop these products, customer expectations must be translated into technical requirements.

With the increasing functionalities of products in recent years, the customer's expectations regarding his interaction with the product and its behavior in different environmental conditions have also become more extensive. Current approaches of model-based systems engineering (MBSE) succeed in developing complex mechatronic products seamlessly from requirements to functions and solutions on a parameter level. However, there is a lack of approaches that systematically translate complex customer expectations into functional and subsequently into technical requirements as a starting point for further development.

In this contribution we present a method that allows to systematically capture the combinatorics of different stakeholders and their expectations as well as different environmental conditions and constraints, to combine them into operational scenarios. From these operational scenarios satisfying explicitly articulated and unknown needs, our method can derive systematically necessary functional and design requirements. By leveraging the established modeling language SysML, existing approaches for the function-oriented model-based system development can benefit directly from these formally modeled requirements.

We applied and evaluated our method in an interdisciplinary, industrial project using the example of a thermal management system of a battery electric vehicle. Our publication signposts the potential for systematic and formal translation of combinatorial customer expectations into operational modes and their requirements and thus enables a targeted, customer-centric and function-oriented development of mechatronic systems.

Classification of function-oriented solution elements for MBSE

Patrick Jagla

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Abstract: Many different engineering models are used in the development of technical systems such as the electro-mechanical drive train. The goal of utilising these models is to predict the physical behaviour of the system by virtually testing it. Already existing engineering models have to be identified and reused, to increase the efficiency of the development process. The model-based systems engineering (MBSE) approach motego [1, 2] supports the development of mechanical systems in a holistic and function-oriented manner. The system solution and the solution element are core elements in motego, that realise specific functions. The solution element contains the principle solution and domain models (e.g. engineering models), while the system solution contains solution elements and domain models. The system solution and especially the solution element provides a meaningful structure for organising and reusing models.

However, in literature those solution elements are not identified and structured yet. This is also true for the electro-mechanical drive train, which is used as case for this study. It is assumed the solution elements can be identified by analysing the interaction between active surfaces of parts in contact. This contribution proposes a classification procedure for solution elements, which is based on elementary functions and principle solutions as they are elements of established development methods.

Systems Engineering: Function-Oriented Development

Modeling Language for the Function-oriented Development of Mechatronic Systems

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Abstract: As mechatronic products gain in popularity, methods for mastering the complexity of these systems in development become increasingly relevant, such as model-based systems engineering (MBSE). Main pillars of MBSE are method, language and tool. A method specifies procedures in product development. The application of the method is supported by a language and tool as the language specifies a system of symbols with which development artifacts can be represented in a software environment (i.e. tool). Currently, various MBSE methods exist, such as motego. Motego specifies a framework for the function-oriented seamless development of mechatronic systems from requirements to the physical realization down to mechanical and electrical contacts and the description of these via parameters and models. Central element in MBSE is the system model, which connects all relevant development artefacts. The system model is created with a language in a software environment such as Cameo Systems Modeler. In MBSE, the graphical systems modeling language SysML is widely established. The language elements in SysML are very abstract and numerous. As a result, the language is difficult to apply. However, its reasonable applicability is an essential prerequisite for the introduction of the motego methods in industrial practice. This results in the following research need: A specific modeling language for the motego method is needed that supports its reasonable application. Therefore, in this paper a modeling language is presented whose language elements are specifically adapted to the motego method. With the help of this domain specific language, the user is guided through method-compliant modeling.

Implementing digital twins of electric drives in existing infrastructures.

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Abstract: Digital twins can offer various added values for companies. As part of a three-year research project, we are investigating the methodological approach, concepts and models for building digital twins. The use cases addressed are the extension of business models, feedback to design, condition monitoring and analytics of high-performance electric motors. Within the framework of this publication, we discuss the methodology pursued, the models and concepts created with regard to their further application in other use cases. Initial insights were gained in the simultaneous development of digital twins in parallel projects with use cases for process monitoring and maintenance of gas turbine components.

In detail, it becomes clear that software development methods (e.g. use cases, user stories, scenario development) are a good way to describe the expected added value functions. It is essential to involve the future users in the development as early as possible. Transferring the necessary functions identified in this way into a functional architecture shows that this architecture is mostly independent of the use case. Likewise, the IT systems used here hardly vary at all. On the other hand, the variance in the design of the necessary information models and functions is completely different. In the context of information model design, integration by means of ontologies is usually the best option because of the heterogeneous data management. The design of the functions is largely determined by the expected added value. By using pipeline systems with no- and low-code concepts, the experts are enabled to define the twins themselves for the most part without having to tie up resources from the IT departments. Overall, it shows that a methodical approach can be followed in the development and the implementation can have a high degree of similarity, even in very different use cases, while the design, depending on these use cases, is very diverse.

On identifying possible Artificial Intelligence Applications in Requirements Engineering Processes

Simon Dehn

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Abstract: Function-oriented development processes need consistent and redundancy-free requirements to be successful. The automobile industry is driven by high customer expectations as well as strict regulatory frameworks that lead to increasing product complexity and a rising number of requirements. Defining and managing requirements in function-oriented development processes result in numerous interfaces across departments and the usage of various distributed data sources. Consequently, Requirement Engineering (RE) processes tie up large amounts of manual workforce capacities.

As requirements primarily exist in the form of written text, Artificial Intelligence (AI) methods provide a promising approach to support RE processes. Based on their capability of processing natural language data and with vast amounts of training data available from existing requirements, AI methods have the potential to automatize specific tasks in RE. However, each RE process is highly individual and consists of many heterogeneous tasks. To broadly integrate AI methods in different RE processes it is necessary to identify the tasks that are suitable for the application of AI.

In this paper, we present a systematic approach using a set of standardized elementary process steps to identify AI application opportunities. We define elementary process steps that enable the abstraction of individual tasks in RE processes by representing them as standardized input-output models. This allows for a precise and homogeneous description of RE processes. Based on the input-output models, capable AI methods can be linked to the corresponding elementary process steps. Ultimately, this leads to a systematic identification of AI application opportunities in RE processes. This approach was developed based on real RE processes in a collaborative research project with industry participation and is discussed in this paper using a concrete example.

Systems Engineering: Processes, Methods and Tools II

Smart Energy – A System of Systems Engineering Perspective

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Malte Stimming, UNITY AG

Abstract: The growing demand for energy, the simultaneous need to reduce climate-damaging emissions, and the advancing digitalization and decentralization increase the connectivity and dependency of formerly simple interrelationships in the energy industry. As a result, the energy industry of the future is a "system-of-systems" and requires an additional toolbox, that of systems engineering, to manage these interdependencies. The context of "Smart Energy" of the future, an application method and use of a common language of stakeholders are shown below.

Towards a Modular Structure for Solution Concepts in MBSE System Models

Gregor Höpfner

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Abstract: The increasing complexity of multidisciplinary products is a major challenge in product development. In recent years, function-oriented model-based systems engineering (MBSE) has emerged as a promising approach for developing complex multidisciplinary products. In function-oriented MBSE, seamless development is carried out by linking requirements, functions, logics and the product in central system models. In the logics layer, solution concepts are modelled and virtually validated against requirements using physical behavior models.

Current research regarding solution concept modelling focuses on linking functions and single solution concepts in the Systems Modeling Language (SysML). In addition, in some modelling methods, physical behavior models and test workflows are linked to solution concepts. However, a product usually consists of various solution concepts on different system levels, which in turn consist of linked sub solution concepts. For example, the solution concept “electric motor” contains the concepts magnetic air gap and rolling bearings, which consist of different kinds of mechanical contacts. A method to structure such aggregated system-level concepts and their models in a modular architecture is not yet given.

This paper presents an approach to systematically model system-level concepts in SysML system models using system solutions. System solutions are aggregated from sub-level system solutions or single solution elements and enable modelling solution concepts in all hierarchy levels, including models and workflows integrated in the system solution. The system solutions are extended by additional models and workflows to describe the characteristics on system-level and to consider emergence effects. The approach is demonstrated on the example of an electric engine with the sub-solutions rotor, stator, air gap, and bearings. The proposed system solution structure is modular, extendable by sub-solutions and models as well as simple to understand.

How generative engineering enables the transition from a documented based to a model-based engineering

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Abstract: Model-based engineering (MBE) is a methodology that uses models to design and develop complex systems, rather than traditional document-based methods. MBE offers several benefits over document-based methods, including better collaboration, more efficient communication, and the ability to quickly iterate and optimize designs.

However, implementing MBE can be challenging, particularly for engineers who are accustomed to traditional document-based methods. To address these challenges, low-code technology has emerged as a key tool for implementing MBE in a practical way.

Low-code platforms use visual and declarative programming tools to enable engineers to quickly and easily create applications, workflows, and business processes, without having to write extensive lines of code. Low-code platforms can also support agile hardware development by allowing engineers to rapidly prototype and iterate their designs, and to collaborate with other team members more efficiently.

In this session, we will explore the benefits of low-code technology for implementing MBE and will also showcase real-world examples of companies that are successfully implementing low-code technology for MBE and agile hardware development. For example, leading aerospace and automotive companies who are using a low-code platform to develop products, which enabled them to quickly iterate and optimize their designs, and to achieve significant time and cost savings.

We will also discuss the role of low-code technology in supporting digital transformation, particularly in the context of agile hardware development. Digital transformation in engineering involves using new software and processes to fundamentally change how a company operates and delivers value to its customers. Low-code can support the digital transformation of engineering by enabling companies to rapidly develop new applications and workflows, and by providing a platform for continuous improvement and innovation of hardware development.

By the end of the session, participants will have a practical understanding of how to implement MBE using low-code technology, and how to leverage low-code technology to support agile hardware development and digital transformation. They will also have a greater appreciation for the benefits of MBE and low-code technology, and for the importance of embracing digital transformation in order to stay competitive in today's rapidly changing business landscape.

Additive Manufacturing Production and Controlling Model

Jan Niklas Schmitz

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Abstract: The study presents an approach that enables cost forecasting for powder-based additive manufacturing (AM) processes using Production- and Controlling Models. The objective is to make manufacturing costs determinable early in the model-based development framework “motego” to allow well-founded decision-making regarding the use of AM. The contribution presents a Production Model of a low-fidelity level, implemented in SysML to predict the manufacturing time based on height and width of a part. The estimated time is transferred to the developed Controlling Model for AM. In this parametric model, the cost structure of powder-based AM processes is implemented on a medium-fidelity level. The cost structures are integrated according to the current state of the art, including the opportunity to define company-specific Pre-, In- and Post-Processing factors. By combining the low-fidelity Production Model with the medium-fidelity Controlling Model, the presented approach allows to estimate manufacturing costs for AM in seconds with an acceptable uncertainty early in the development process. Consequently, the procedure can be used to support cost-efficient model-based development processes for AM.

Drivetrains: Noise Vibration Harshness

Combining sensitivity and uncertainty analysis to efficiently quantify parametric uncertainties in NVH system simulation models

Stefan Wischmann

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Abstract: The acoustic and structural dynamic properties of vehicles—often referred to as Noise, Vibration, Harshness (NVH)—form a crucial criterion during product development. To reduce iterations with physical prototypes, NVH simulation models are well established. In early development phases, many parameters of NVH models, such as material and contact properties, are either assumed based on empirical values or have to be measured. In both cases, the value of these parameters is uncertain. Thus, the output of NVH system simulation models such as structure borne or air borne sound is also uncertain and must be quantified. However, applying state-of-the-art uncertainty analysis methods to NVH simulation models considering all uncertain input parameters is inefficient due to their high computation time. Therefore, this paper presents a method of coupled sensitivity (SA) and uncertainty analysis (UA), which enables the efficient uncertainty calculation for NVH simulations. In this method, firstly the most influential parameters are determined using a SA to reduce the number of input parameters. Depending on the number of parameters and the computation time of the NVH simulation model, either the Morris SA or an EFAST SA is chosen. Finally, a fuzzy UA is performed, which quantifies the uncertainty of the output of the NVH simulation and provides its possible ranges. The procedure is applied to the NVH model for predicting air borne sound of an electric drive with 53 uncertain input parameters.

MBS model validation of an industrial gearbox for predicting vibro-acoustic behavior

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Abstract: Flexible Multi Body Simulation (MBS) models are increasingly employed in the early stages of product development for predicting and analyzing the vibro-acoustic behavior of gearboxes. The accuracy of the predictions is heavily dependent on the accurate modelling of the individual flexible bodies, bearings, joints, gear wheels as well as meshing excitation. Therefore, this paper aims to demonstrate the systematic experimental validation of the component and assembly dynamics of an exemplary industrial gearbox model. The considered gearbox is modelled using a commercial MBS software and the validation is conducted in increasing order of complexity of components. For describing the vibro-acoustic behavior, it is not only necessary to validate the dynamic behavior of the assembly but also to accurately represent the dynamic excitation from gear meshing. For this, metrological inspections were conducted for the gearbox housing, shafts as well as gearings. The resulting axis deviations, shaft inclinations and gear profiles were considered in the MBS model. Subsequently, the predictions of surface velocities at distinct points on the gearbox during operation are compared with corresponding experimental measurements.

Non-parametric shape optimization for electrical machines: Lowering noise and vibration effects by reducing selected radial force waves

Christian Kremers

Dassault Systemes

Abstract: Electric vehicle purchasers demand a quiet, comfortable ride as well as long range and good performance. The electric motor is one of the main sources of unpleasant noise and vibration (NV) in an electric vehicle, and so there is a lot of pressure on engineers to make their designs as quiet and smooth running as possible. At present, mainly parametric optimization approaches are in use for optimizing electrical machines. This contribution introduces a non-parametric optimization technique to be included in the design process to improve the electrical machine's overall performance with respect to both torque performance and NV behavior.

Multi Body Simulation of Electric Drive Trains

Tamir Dombrovskij

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Abstract: Failures of machine elements can cause critical machine breakdowns, e.g. bearing damage accounts for almost 20% of all machine failures. Hence, monitoring machine elements is of particular importance for condition monitoring of gearboxes. Therefore, new approaches based on electrical impedance analysis are proposed in literature, e.g. for the measurement of rolling bearing load or damage condition with so-called sensory utilizable machine elements (SuME). For this approach, an electrical signal is transmitted through the structure to be observed and the resulting impedance is measured. With this technique it is possible to detect loads and damages not only for bearings, but also for the entire gearbox. Another application of this method can be the transmission of electrical signals through machine elements and the gearbox themselves. However, uncertainty arises with regard to the distinct signal transmission in these processes, mainly due to parasitic capacitances. In this contribution, the disturbing factors on the measured impedance of a gearbox at different working points are investigated. For this purpose, disturbance factors are systematically identified and used as basis for a full factorial experimental design for screening the operational characteristics of a gearbox. The data obtained from the tests is analyzed to identify correlations between the disturbance factors and parasitic capacitances. The experiments show a speed- and torque-dependent behavior of the parasitic capacitances in a gearbox. These results can be used for further research of SuME and structure-integrated energy supply and signal paths as well as the evaluation of related measurement data by reducing the associated uncertainty.

Model-Based NVH Optimization of a Tractor Drivetrain During All Phases of the Development Process

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Abstract: The modern, ever shorter development process of powertrains incorporates many different disciplines of mechanical engineering. Among these, the dynamic and acoustic behavior - which is often referred to as noise, vibration, harshness (NVH) - is becoming increasingly important for the consumer's purchase decision. However, NVH is often only considered in the last steps of the product development as both experimental NVH analysis methods and high-fidelity NVH modeling approaches, such as elastic multi-body simulation (eMBS), are complex and time-consuming. Especially in early phases of the development process, fast iteration cycles are crucial. Thus, the design engineer needs appropriate NVH models for each phase of the development process in order to evaluate design and concept decisions with respect to their NVH implications.

This publication shows a methodological guide on how to apply suitable NVH models in all stages of the development process and thus efficiently implement optimizations. In the early, highly iterative phases of the development process, analytical analyses of the excitation behavior as well as simplified finite element simulations are carried out in order to estimate the vibration behavior of the concept. For the first elaborated geometries, frequency response functions can then be determined and thus the influence of e.g. ribbings to NVH behavior can be evaluated. In the later phases of development, where advanced simulation models have to be set up also for other disciplines, such as fatigue strength, a fully parameterized eMBS model of the powertrain enables an analysis of the operating behavior of the system, from which further optimization potential of the system can be derived. The engineer is thus able to apply a suitable NVH model for each phase of the development process with time and accuracy suitable for the phase. The proposed method is demonstrated on the application example of a tractor transaxle development process.

Drivetrains: Performance and Efficiency

Multi-Motor Drive Technology in the Multi-Meganewtonmeter-Range

Jonas Reicherter

Renk Test System GmbH

Abstract: RENK has been successfully manufacturing multi-motor drives and generators for a wide variety of industrial applications for many years. Based on this, RENK Test System GmbH (RTS) is now developing a 35 MW drive with a maximum torque of 43 MNm for a wind turbine test stand.

The concept of the multi-motor drive is used for applications with extreme torques and maximum operational readiness required. The arrangement of several electric motors to a single compact drive enables a resulting torque that is otherwise only possible with high-risk and high-cost special solutions in motor design, such as direct drives. However, the arrangement of a number of standard motors in combination with proven RENK gear technology results in a system of highest reliability and lowest costs.

This paper will focus on the various applications this drive technology is already in use, as well as the challenges running a test bench with it. Such as backlashing and control dynamics. Another focus within this paper will be the virtual commissioning of the test rig with our digital twin technology.

Validation Environment for S-Pedelec Wheel Hub Motors

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Abstract: The validation of technical systems is the central activity of product engineering. In order to validate a system, the requirements of users and other stakeholders must be compared continuously with the current state of the system. In the development of e-Bikes, which are becoming increasingly popular, a central gap is emerging: There is hardly any field data to compare the system behavior against realistic loads.

Increasing drivetrain efficiency by innovative gear design, optimized gearbox design and integration of smart sensors

Jan Reimann

Flender GmbH

Abstract: The selection of single-stage gear units for a drivetrain is depending on thermal power limit of the gearbox itself. Optimizing thermal power limit by new gear geometry design, balanced bearing selection and new housing concepts leads to significant efficiency increase of the gear set and gearbox. Thereby, in the end the whole drivetrain. The objective of this paper is to demonstrate how modern gear and housing design can achieve higher efficiencies than the state of the art and how this can have a positive effect on the overall efficiency of the powertrain.

Systems Engineering: Virtual Validation and Optimization

Framework for Seamless and Interoperable Linking of Components and Simulation Models for Fluid Power Systems

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Abstract: Increasing product requirements and complexities require an optimized simulation model-based product development process. The current process is characterized by a lack of linkage within the individual product development phases, a lack of linkage between component data and simulation models, and a lack of cross-stakeholder availability of technical know-how regarding simulations and simulation models. These deficits are addressed in this contribution by introducing a concept for seamlessly linking of components and simulation models. In addition to the mentioned deficits, the concept should lead to a reduction in the time required as well as a lower susceptibility to errors in creating simulation models.

Seamless linking of components and component simulation models is realized based on the Asset Administration Shell (AAS). Based on the AAS data model, three functionalities for improved linking of components and simulation models have been developed. The first functionality enables searching and finding component data or component simulation models from repositories of relevant stakeholders. The second functionality enables domain- and tool-independent integration of simulation models in a simulation environment by using an automatic parameterization of simulation models or directly integrating Functional Mock-up Units (FMUs). Lastly, the third functionality enables bidirectional synchronization between field devices and simulation models.

Reusable workflows for virtual testing of multidisciplinary products in system models

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Abstract: Developing increasingly complex multidisciplinary products in short development cycles is one major challenge in today's product development.Model-based Systems Engineering (MBSE) approaches are well suited to address this challenge. With MBSE, products are virtually represented in central system models. For the efficient verification of customer requirements and to avoid exhaustive physical testing with prototypes, virtual domain models (e.g. FE-models) are integrated into the system model. To perform a virtual test, domain models need to be executed in a sequence, so-called workflows. Current workflows link several product system levels in one workflow and are often only valid for one specific system architecture. As the number of requirements and system complexity increases, these workflows become also more complex. The effort for creating new comprehensible workflows is currently high and the reusability cannot be ensured. To solve these deficits, a method for the systematic formalization of reusable workflows in system models as well as their structured integration is presented. Behavior diagrams in the modelling language SysML are used to control the execution order of the domain models of different purposes and fidelities. Modular sub-workflows are developed for each system level. These sub-workflows can be reused and combined modularly to form larger workflows. The approach shows a high potential to easily build and organize workflows in reusable libraries thereby supporting automated virtual testing in product development. To demonstrate the approach, workflows for bearing lifetime calculation and shaft fatigue testing of a wind turbine drive train as well as their integration into the SysML system model are presented.

Combining and evaluating function-oriented solutions in model-based systems engineering

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Abstract: Increasing complexity and shorter innovation cycles require a rethink in the development of mechatronic products. A function-oriented development process using model-based systems engineering (MBSE) methods promises to identify technical solutions via solution-neutral functional architectures. Since each function can typically be realized by multiple, alternative solutions the combinatorial number of overall system solutions explodes. Existing MBSE approaches enable to establish functional architectures as well as support the verification of solutions. However, evaluating different solution combinations with the current state of research involves repetitive and time-consuming modeling which leads to a heuristic selection of potentially suboptimal solutions. In this paper, we present a method for the systematic and function-oriented composition and model-based evaluation of solution combinations. Alternative solutions are structured based on a functional architecture, so that each possible solution combination can be composed and simulated with a minimum of effort, considering physical interactions and the efficiency. Based on simulation results, solution combinations can be verified against requirements and evaluated striving for the best solution combination. The elaborated method extends an existing MBSE approach and is illustrated by the running example of an electrical coolant pump of a passenger vehicle.

Multi-Objective Yield Optimization for Electrical Machines using Machine Learning

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Dassault Systèmes

Abstract: This work deals with the design optimization of electrical machines under the consideration of manufacturing uncertainties. In order to efficiently quantify the uncertainty, a hybrid Gauss-Process regression (GPR) model is employed. In contrast to classic Kriging or Bayesian optimization approaches, we train a GPR surrogate for the performance feature specifications, not for the objective function. A multi-objective optimization problem is formulated, maximizing simultaneously the reliability, i.e., the yield, and further performance objectives, e.g., the costs. A permanent magnet synchronous machine is modeled and simulated in commercial finite element simulation software. Four approaches for solving the multi-objective optimization problem are described and numerically compared, namely: ε-constraint scalarization, weighted sum scalarization and a multi-start weighted sum. We show that the efficiency gain thanks to our hybrid GPR model enables even computationally heavy multi-objective optimization for real-world applications.

Systems Engineering: Surrogate Models

An investigation into the transferability of dynamic elastomer damper's properties between different damper sizes using FEM

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Abstract: Elastomer dampers are used in drive systems to systematically adjust the systems' vibration behaviour, by lowering resonance frequencies through their low stiffness. Selecting the right damper therefor requires model-based prediction of the system's vibrations. Modelling elastomer dampers in the system context involves a high degree of complexity, since non-linear material effects in elastomers, such as the dependence of material properties on loading speed and history, make it difficult to calculate the coupling's stiffness. This complexity hinders the model parameters of elastomer dampers to be determined from physical parameters such as material composition and geometric quantities. Instead, abstract models must be used that represent the material behaviour phenomenologically and are parameterized via experimental investigations on each individual damper. The diversity of variants and custom production mean that manufacturers and industrial users of elastomer dampers are confronted with a disproportionately large number of required experiments.

The aim of the proposed method is to reduce the number of required experiments by inferring the behaviour of various different elastomer dampers from experiments on a single damper. For this purpose, it is assumed that separating the influence of the damper's geometry and the influence of the material is possible, while the geometries' influence can be predicted by abstracting parts of the phenomenological model via a FE model. The method is exemplarily demonstrated on a torsional loaded elastomer coupling. The coupling is investigated in a (quasi-)static and dynamic experiment and a (quasi-)static simulation. By mapping the measured (quasi-)static torque on the simulated torque via the torsional angle, the behaviour of differently-sized couplings can be inferred via (quasi-)static simulations. The method is validated by comparing the predicted and a measured dynamic behaviour of differently sized couplings.

Surrogate model based prediction of transmission error characteristics based on generalized topography deviations

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Abstract: Simulation models of the tooth contact can provide valuable information of the gearbox operational behavior for deviated gears. It is therefore possible to gather geometry and deviation information of the two gears in contact and then estimate how they will perform in the assembled unit before even mounting them. This procedure could save time and costs used to disassemble gear boxes which fail the end of line tests because of acoustic reasons. The major challenge using sophisticated simulation models, which can describe the tooth contact is the tremendous amount of calculation time they need to produce suit-able results. In a productive gearbox manufacturing process this time is just not available. Therefore, a method to predict the operational behavior faster, than with the current used simulation models is needed. Firstly, the size of the problem is downsized by introducing the sum deviation surface. It allows to reduce the number of necessary input parameters for a gear topography description to eighteen factors. With the help of that sum deviation surface, 3000 variants within a given variation space are calculated. The resulting training dataset is used to develop a deep neural network meta-model of the gear contact, which can predict the characteristics of the transmission error under load. With the help of that meta-model, the excitation of a gear pair can be predicted faster than real-time.

A meta-model for prediction of maximum temperature within a lubricated line contact

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Abstract: Roller bearings are used for a wide range of applications. Under severe conditions, the roller-race contacts within a bearing are subject to high-temperature rise. Smearing is a type of surface damage associated with high contact temperatures. In this paper, we propose an approach for a meta model predicting the maximum temperature within line contacts in mixed lubrication. A meta model approximates a high-fidelity model that is used when time, cost, or computational effort must be reduced.

A literature review is conducted and current state-of-the-art analytical models are implemented. The results are compared with the results from a thermo-elastohydrodynamic lubrication (TEHL) solver. The TEHL solver is used to generate training data and evaluate the meta-model. The training data of the meta-model covers a wide range of parameters.

TEHL simulation enables detailed modeling of flash temperature. However, the computational cost is high. The developed ANN model can predict the temperature with higher accuracy than the existing analytical models. The correlation coefficient (R) for the trained model is higher than 0.997. The influence of different network architectures on the accuracy is shown. Furthermore, the impact of feature engineering on the prediction accuracy with limited data sets is presented.