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Book of Abstracts

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101 - Predicting the Behavior of Spherical Roller Bearings with a detailed Multi-Body Simulation Model

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Keywords: Rolling Bearing, Spherical Roller Bearings, Multi-Body Simulation

Introduction

There are several approaches to making a mechanical system more sustainable. One of the most important is to reduce friction losses and extend the service life of the system. To achieve this, not only must each mechanical element be considered individually, but above all the interaction between the elements. An important tool that makes this possible and can also take dynamic loads into account is multi-body simulation (MBS). Rolling bearings are an important component of transmission systems. They can excite the mechanical system and their behaviour is heavily dependent on the dynamic loads, induced by the meshing of the gears.

For this reason, the software called LaMBDA was developed at the MEGT. It consists not only of a graphical user interface with which detailed models of rolling bearings can automatically be created for the software SIMPACK, but also of user-defined force routines in which the contact forces within the rolling bearing are determined. It enables a better understanding of dynamic behaviour such as slip or the interaction between rolling elements and cage or rib. Following the modelling of deep groove ball bearings, cylindrical roller bearings and tapered roller bearings in the past, a multi-body simulation model for spherical roller bearings (SRB) has now been developed in an ongoing research project funded by German research association for drive train technology (FVA).With this tool, it is possible to precisely understand the dynamic behaviour and thus also slip and wear - both very common phenomena in spherical roller bearings, due to the two rows of rolling elements. When the SRB is axially loaded, the slippage in one of the rows can become critical and lead to smearing or other slip-induced damage.

Multi-Body-Simulation

In addition to the modelling of the bodies themselves the most accurate calculation of the contact forces and torques between the component is essential. To obtain an accurate prediction of bearing friction, special attention must be paid to the friction

calculation. It is therefore essential to take all friction effects in each contact within the bearing into account. Figure 1 shows the different types of tractions and losses and how they are combined to model mixed friction. In this context, MBS is faced with the challenge of mapping the friction effects as accurately as possible, while at the same time ensuring that the calculation is numerically stable and efficient. The developed model meets these requirements.

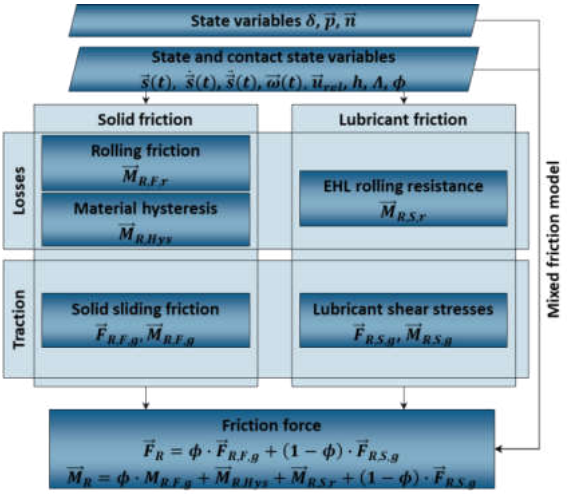

Figure 1: Flow chart of friction force calculation between rolling elements and ring raceways [1]

Several comparisons regarding the force and pressure distribution of the model with comparable software were successfully carried out and the frictional torque calculated by the model was validated using measurements at different radial, axial forces and speed on a torque measuring rig.

As mentioned in the introduction, the information resulting from the simulation about the kinematics of the cage and the rolling elements enables a prediction of wear that is not possible with classical calculation methods.

As the model is parameterized and modular, its geometry can be easily modified, allowing a better understanding of its influence on overall efficiency of the SRB.

Finally, the SRB model can also be integrated into MBS models of entire drivetrains, and by changing the bearing size, type or arrangement, the system can be optimised, resulting in a more sustainable product.

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201- A collaborative robotic application for the assembly of car rear lamps

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Keywords: collaborative robotics, assembly, trajectory planning, speed and separation monitoring, cycle time optimization

In this work we present the automation of the sticking of small components on car rear lamps, a swift and repetitive operation that is currently performed manually by an operator. The challenging automation of this process includes the delicate pick and place of tiny items in predefined positions on the rear lamps. Pick-and-place trajectories for the robot are planned and a custom end-effector is designed to accomplish the task. Furthermore, a safety approach is implemented to stop the robot in the event of a potential collision with the human operator. Finally, the impact of the cycle time on quantitative metrics for human-robot collaboration, as well as on the mechanical energy of the robot is evaluated. Experimental results on a UR5e manipulator show the feasibility of the operation, while meeting the robot constraints and the cycle time requirements.

301 - Artificial intelligence - Insights into the mechanics of biomaterials: Predicting the compressive load of composite sandwich structures

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Keywords: Machine learning analysis, Bio-composite structures, Random Forest, Ridge regression, Mechanical property

This research investigates the mechanical behavior of novel environmentally friendly composite sandwich structures using machine learning techniques. The experiments were conducted to evaluate the effects of geometrical dimensions on the strength of the proposed sandwich panels as a load-bearing structure. Random forest and ridge regression methods were used to characterize the effect of geometric dimensions on the compressive strength of the natural composite sandwich structures. A comprehensive dataset of 42,260 test results was created and processed to train and evaluate the machine-learning models. Key parameters affecting the compressive strength of bio-based composite panels include the number of cupules, the height, diameter and thickness of the cupules, and the properties of balsa wood. The results show the accuracy of the developed models in predicting the mechanical behavior of composite materials under certain loading conditions. The analysis of the importance of the feature contribution shows that the number of cupules has the greatest influence and the mechanical properties of the balsa wood have the least influence on the compressive strength of the composite panels. The investigation of the compressive strength of sandwich panels made of natural composite materials under quasi-static, out-of-plane loading conditions facilitates the creation of accurate prediction models and design guidelines for their optimal use in various applications.

102 - Flows in Oil-Bath Lubricated Tapered Roller Bearings: CFD Simulations Validated Via PIV

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The operation of Tapered Roller Bearings (TRBs) in oil-bath lubricated systems involves relevant lubricant flows. For example, the axial oil flow from the small end to the large end of a TRB is renowned as pumping effect. This effect, which has been studied since the 1970s [1], influences the design of lubricant supply. In addition, it affects system cooling, static pressure on seals, and no-load dependent Power Losses (PLs). In the last decade, Liebrecht et al., (2015) [2] investigated the drag and churning losses on a TRBs through a dedicated test rig. In addition, the scholars developed a Computational Fluid Dynamics (CFD) model able to estimate the PLs and predict the lubricant flows. However, although the model has been validated experimentally for the evaluation of PLs, it has not been validated in terms of oil flows. Nevertheless, Liebrecht et al., (2015) [2] did not discuss in depth the results of the flows they obtained through CFD.

In recent years, Maccioni et al., (2022) [3] were able to experimentally measure lubricant flows within a dip-lubricated TRB via Particle Image Velocimetry (PIV). Data showed that as rotational speed increases, aeration becomes a significant effect. Therefore, through these data, Maccioni et al., (2022) [4] was able to validate different CFD models. More specifically, in dip-lubrication, at low rotational speeds, a single-phase solver can be used to faithfully estimate the internal fluxes [5]. As rotational speed increases, the most consistent results with the experimental evidences are obtained by implementing a solver with an aeration model i.e. (Hirt & Nichols, 1981) [6].

However, although dip-lubrication is the only condition for reliable PIV measurements, this situation is rarely employed in real applications of TRBs. Therefore, in the present paper, the validated (in dip-lubrication) two-phase with aeration model have been applied to oil-bath condition at different rotational speeds. The same boundary conditions have been solved with a two-phase model that does not include aeration. The results in terms of fluxes, PLs and computational effort of the two models have been compared and discussed.

Preliminary results show that in oil-bath lubrication of TRBs, it is possible to identify two separated volumes within the bearing where air and oil have different behaviors. On the one hand, the pumping effect of the oil occurs mainly in the volume near to the outer ring. On the other hand, air aspiration from the large end to the small end of a TRB is always present. This occurs mainly in the volume near to the inner ring. This effect, never mentioned in the scientific literature, has fundamental repercussions on lubrication and cooling of TRBs. Indeed, the highest speeds are reached in the contact between the inner ring and rollers. Therefore, the presence of lubricant in that contact is essential for long life design. If in classic oil-bath lubrication this area is mostly

engaged by air flows, it is necessary to create specific features in the chamber connected to the major section of the TRB to allow the oil pumped from the outer part of the bearing to fall back into the innermost part. Based on the above mentioned results, to improve the efficiency of oil jetting of TRB, it may be more effective to use jets positioned on the side of the larger section near the inner ring, rather than in the opposite side. In this way, airflow does not oppose the jet's inflow into the bearing.
With respect to the chamber connected to the minor section of the TRB, the simulations shows that air mixes with oil in this volume. This mixing has a decisive effect on the properties of the oil, which will then be subject to the pumping effect. Changes in oil properties are taken into account by the aeration model.

202 – An Excel motion profile optimization (MoPO) tool for industrial positioning applications

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Keywords: Excel tool, motion profile optimization, energy-efficient, trajectory planning, mechatronic systems

Repetitive positioning applications are of significant importance in industrial machinery. The electric actuators driving these movements account for a substantial portion of worldwide energy use. Therefore, it is valuable to consider optimizing these movements. This is further underscored by the increasing pressure on machine builders to enhance productivity and decrease vibrations during operation. In this context, motion profile optimization is a cost-effective solution, allowing for more energy-efficient machines without additional hardware investments. The state-of-the-art contains several valuable optimization algorithms to reduce energy, resulting in torque savings up to 45.4%. However, these methods rely on specific software which might require expertise and additional license investments. The latter hinders the adoption of motion profile optimization in many companies' engineering workflow. After surveying 36 machine builders, it became clear that only 11% of them confirmed having in-depth expertise to perform motion profile optimizations. Therefore, an exclusively Excel-based Motion Profile Optimization (MoPO) tool is introduced. The MoPO tool eliminates the need to invest in auxiliary software packages other than Computer-Aided Design (CAD) software, which machine designers already use. Moreover, the tool features a user-friendly interface and ensures compatibility with widely used drive software, enhancing its practical utility for machine builders. The MoPO Excel tool is able to achieve identical savings as commercial optimization software, such as MATLAB. After proposing the techniques, 74.1 % of the machine builders rate the applicability as good or very good.

302 - Estimating Colebrook-White friction factor using tree-based machine learning models

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Keywords: Friction factor, Colebrook-White, Machine learning, water supply, decision tree, Gradient Boosting, XGBoost

Colebrook-White friction factor is the common hydraulic roughness coefficient used in water supply systems. Analysis, design, and management of water distribution networks basically rely on an adequate estimation of friction factor. In turbulent flows, it depends on the Reynolds number and the relative roughness of pipes. This study assesses the performances of four tree-based Machine Learning (ML) models, including Decision Tree (DT) Regression, Adaboost, Gradient Boosting Regressor (GBR), and XGBoost. Their performances were compared with the equation of Swamee-Jain, which is utilized in EPANET hydraulic solver. For the comparative analysis, a reliable database comprising more than one million data points in the turbulent flow zone. Based on the results, GBR and DT performed better than the equation of Swamee-Jain. The improvement made in friction factor estimations using ML-based suggests further studies on the topic. Thus, future studies can be conducted by implementing ML-based estimator in hydraulic software for simulating pipe networks.

103 - Spherical bearing with tapered hourglass rolling elements for planetary reduction stage applications

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Keywords: Planetary Stage, Spherical Bearing, Tapered Hourglass, Helicopter Gearbox, Loss of Lubrication

Safety and the continuous safety improvement are fundamental drivers of the constant innovation process of the rotary wing aircraft design. Current certification rules, applicable to civil helicopters, fully embody this purpose: in particular, during last decades, the certification standards have progressively become more and more demanding about the capability of the drive system gearboxes to operate in a loss of lubrication condition, both in terms of power conditions and time to be demonstrated.

When a power gearbox completely loses the lubricant, gears and bearings quickly become powerful heat sources capable of damaging internal components up to compromising the functionality of the system and to jeopardizing safety of flight.

In the last years, helicopter manufacturers worldwide have developed several strategies to overcome the risk associated to the loss of lubrication condition, with the aim of making their drive systems able to operate as much as possible under these extreme conditions (i.e. use of high temperature resistant materials and auxiliary oil reservoirs design arrangement).

Leonardo Helicopter Division (LHD) is part of this engineering challenge; an innovative architecture aimed to actively reduce the heat generated in a planetary re-duction stage during no-oil conditions is presented. In this solution the standard spherical bearings used to compensate misalignments are replaced with novel spherical bearings with tapered hourglass rolling elements.

This theoretical dissertation on technology concerning self-aligning bearings with line contact, basing an excursus on spherical bearings evolution, deals with the rationale that led to the development of this new architecture and its technology development.

203 - Inverse dynamics for feedforward control of an underactuated 6-DOF gantry crane

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Keywords: Inverse dynamics, Feedforward control, Underactuated multibody systems, Internal dynamics, Gantry crane.

Inverse dynamics in underactuated, non-minimum phase multibody systems is addressed in this paper by means of the challenging example of a gantry crane driving a spatial double pendulum. The latter consists of a pendulum plus a spatial rigid body attached to the pendulum terminal mass. The reference to be tracked are the two planar Cartesian coordinates is the rigid-body tip, while the actuated coordinates are those of the trolley. Because of under-actuation and non-flat property of the system, inverse dynamics relies on a mixed algebraic and differential scheme. Additionally, the input-output con-figuration assumed leads to a system, with an unstable internal dynamic, whose integration cannot be done unless stabilization is performed. By exploiting the concept of output redefinition, i.e., by assuming a fictitious out-put in the internal dynamics equations, stabilization is performed, while ensuring excellent tracking performances. Numerical simulations proof the method effectiveness.

303 - Integrated approach for continuous improvement of robotic garments picking

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Keywords: Human-robot collaborative system, Garment detection models, Gripper for garment picking, Garment sorting

The recent trend in the textile setting highlights the need for more effective and affordable processes to make the garment market more sustainable. Secondhand garment reuse and fabric recycling are two virtuous pathways toward material saving and sustainable transition. Sorting processes are fundamental enablers of this transition. The main operations involved are identification, classification, and quality assessment. The current work proposes a collaborative robotic solution for the first identification and classification of garments to support human experts along with the following assessment operations of garment and fabric quality and identification of textile fibers. The proposed approach is based on adopting a collaborative system integrating robots, machine vision models, and dedicated gripper systems to perform the picking actions required to identify and classify garment categories. The first experiments demonstrate the feasibility of the proposed approach as well as the self-learning capability of the system using the detection model continuous training.

104 - Experimental comparison of hydrostatic bearing pad geometry optimization approaches under static conditions

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Keywords: Hydrostatic lubrication, Bearing geometry, Performance optimization

Hydrostatic bearings are widely used in various applications, but their continuous need for externally pressurized lubricant poses energy consumption challenges. This study aims to experimentally compare the performance of hydrostatic bear-ing pad geometry optimization approaches. Using a two-pad hydrostatic tester with online diagnostics, we evaluated optimized multi-recess pads derived from classical and computational fluid dynamics (CFD) approaches. Our findings reveal that the CFD approach achieves a 12% increase in film thickness and a 21% increase in recess pressure compared to the classical approach under equivalent experimental conditions. However, the enhanced performance of CFD-optimized pads comes with increased sensitivity to local overload or misalignment, as evidenced in this study. While adopting the CFD-optimized geometry promises no-table reductions in energy demands, ensuring precise alignment, particularly in large-scale applications, remains critical. In conclusion, our study indicates that employing the CFD optimization approach can effectively lower the service costs of hydrostatic bearings. However, achieving optimal results requires careful attention to alignment.

204 - Chattering-free Sliding Mode Control for Position and Attitude Tracking of a Quadrotor

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Interest in the use of quadrotor Unmanned Aerial Vehicles (UAVs) has been growing due to their high maneuverability in indoor- and outdoor-spaces, low size, and vertical take-off capabilities. Their control is a challenging topic, given the complex, nonlinear, and underactuated dynamical characteristics. Simulations and real-time implementations have shown that one of the most promising robust controllers is the sliding mode controller (SMC). However, the drawback of SMC is the chattering phenomenon, caused by the discontinuity of the signum function included in the control signal [1]. This work proposes a chattering-free sliding mode controller for position and attitude tracking of a quadrotor. Our approach, which is inspired by [2], permits computation of the sliding surface coefficients using a simple linearization of the dynamic model and Hurwitz Stability. As the chattering effect is not addressed in [2], we eliminate the undesired oscillations via approximation with a saturation function. The Newton-Euler approach [3] is used to develop a mathematical model of the quadrotor, in which its translational and rotational dynamics are defined in an Earth-fixed frame $\mathscr{E}$ (Fig. 1).

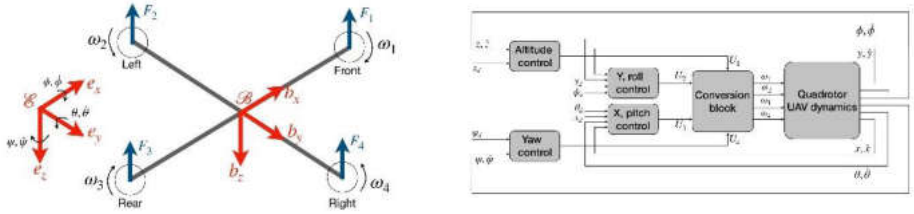
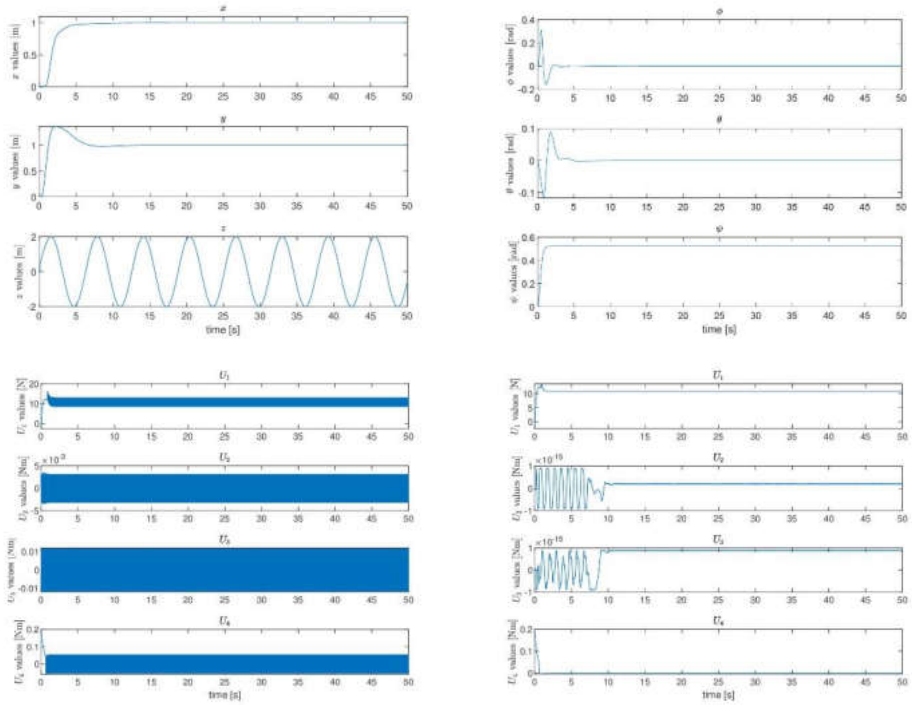


Fig. 1: Quadrotor UAV (left) and control scheme (right)

To achieve asymptotic tracking, the system is divided into two subsystems, a fully-actuated subsystem (FAS) and an underactuated subsystem (UAS), and four sliding mode controllers are designed. The first step is to select a first-order sliding surface associated to the desired behaviour of the system. In this case, each sliding surface S is defined as a linear combination of the corresponding tracking error and its derivative. The second step is to drive the sliding surface to 0. Consequently, the sliding mode control consists of two terms: the equivalent control, which controls the system when the sliding surface is reached and found by imposing $\dot{S} = 0$; and the switching control, which makes S converge to S = 0, by imposing the sliding condition $\dot{S} = -a \cdot sign(S) - b \cdot S$. For the UAS, the coefficients of the sliding manifolds are obtained via Hurwitz stability analysis from the linearized system. Fig. 2 shows the results

for $x_d = 1$, $y_d = 1$, $z_d = 2sin(t)$, $\phi_d = 0$, $\theta_d = 0$, and $\psi_d = \pi/6$. The simulations demonstrate the effectiveness of the proposed controller for both tracking and chattering elimination. The study represents a first step towards the development of robust controllers for trajectory tracking and stabilization of quadrotors with suspended payloads.

Fig. 2: Tracking (top) and elimination of chattering (bottom)



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304 - Automated visual inspection via differentiable physically-based rendering under unknown illumination

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Keywords: Automated Visual Inspection, Differentiable rendering

Detecting defects in manufactured objects is essential for achieving high quality standards. To this purpose, automated visual inspection involves detecting defects analysing images captured by machine-vision systems. Nowadays, most of the methods depend on data-driven approaches. We propose a novel non-data-driven approach for detecting defects concerning the appearance of objects with arbitrary shapes, only requiring the CAD model and the knowledge of material distribution on the surface. We address the task with an inverse rendering approach, employing a differentiable physically-based renderer (PBR). We further estimate ambient-light, making the method able to deal with unknown light conditions in each inspection. Defects can be then localized from the generated heatmap computing the distance between the rendered images and the real ones. In this study, we examine a case involving steel cooling jackets for e-motors, transported by a conveyor belt in a production line. We leverage the motion of the object acquiring images in multiple time instants to increase the number of views. As there are no benchmarks available for comparisons, we provided only qualitative results on a real scenario. We offer a simple solution for visual inspection. It employs a machine-vision system exempt from lighting components, and it does not require data and training models unlike typical data-driven approaches. The proposed method is potentially suitable for online application, such as Digital Twins to monitor quality attributes.

105 - The influence of measurement uncertainties and input parameters on hydrostatic bearing performance: analytical, experimental, and numerical comparison

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Keywords: Hydrostatic lubrication, Thin lubricant layer simulation, CFD simulation, OpenFOAM

Design and real-time control of hydrostatic bearings (HS) demand accurate models capable of reliably predicting bearing behavior under varying operational conditions. Analytical models have proven insufficient to estimate key parameters such as carrying capacity, recess pressure, film thickness, or flow rate simultaneously. To address this limitation, Computational Fluid Dynamics (CFD) has emerged as a valuable tool in recent years. However, the accuracy of operational data measurements, used to set numerical and analytical models, plays a significant role in uncertainty propagation. This study concerns an experimental campaign and the development of a CFD model in the OpenFOAM® environment. To reproduce the experimental conditions, numerical and analytical models are set using different input parameters, i.e. flow rate or recess pressure, considering extreme operational conditions tied to the accuracy of experimental data. Results reveal that, while average CFD values exhibit consistent errors in estimating operational parameters, experimental and numerical uncertainty ranges overlap under the investigated operational conditions. In contrast, analytical estimation leads to clear discrepancies, even when considering measurement uncertainties. Furthermore, concerning carrying capacity estimation, recess pressure emerges as the input parameter yielding more satisfactory results. The findings emphasize the importance of considering measurement uncertainties in setting numerical and analytical models for HS bearings, providing valuable insights for their accurate design and real-time control.

205 - Adaptive vibration absorption using Internal Model Control approach

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Keywords: Vibration absorption, Internal model control, Antiresonant control, Underactuated systems, Multibody systems

Anti-resonant vibration control is a technique that aims to mitigate unwanted vibrations when the system is excited with an exogenous disturbance. Vibration suppression is particularly interesting to avoid harmful effects, like inaccuracy in tool machines and robotics, discomfort in vehicles, and structural damages. Passive, semi-active, or active techniques are widespread in several practical applications. Active approaches have the advantage of being adaptive, i.e., the target frequency of the excitation to be absorbed can be modified. This aspect is fundamental in applications with time-varying disturbances. This paper proposes an internal model control strategy in the context of anti-resonant control for known and unknown frequency of disturbances. Based on some recent theoretical results in the literature, a receptance-based internal model control scheme is proposed to tackle exogenous disturbances that might cause severe vibrations. The approach is applied to control a meaningful example of underactauted multibody system: a two-link flexible-joint robotic arm controlled by just one motor. The numerical results illustrate the effectiveness of the approach.

305 - Egocentric video-based human action recognition in industrial environments

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Keywords: Egocentric Perception, Multimodal Action Recognition, Ensemble Modeling

Enhancing workplace safety and conditions in industrial settings through the recognition of workers' actions is a pivotal area of research. To this end, the MECCANO dataset serves as a unique benchmark, essential for the development of specialized recognition models. This study, representing our notable achievement of second place in the MECCANO 2023 challenge, focuses on developing egocentric multimodal action recognition models tailored to industry applications. Specifically, we employed the Gate-Shift-Fuse (GSF) module, compatible with any 2D Convolutional Neural Network, extending its functionality to RGB and Depth modalities, including a slow-fast inference approach. Our methodology involved training multiple GSF instances with variations in backbone architecture, number of segments, batch size, and number of epochs. An ensemble system integrating these instances through soft and hard voting was developed, achieving a top-1 accuracy of 52.57% and a top-5 accuracy of 81.53% in the challenge. We also engineered and prototyped an action recognition system that employs the trained models.

106 - Decoupled Sliding-Mode Control for active magnetic Bearings using Particle Swarm Parameter Optimisation

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Keywords: Active Magnetic Bearings, Sliding Mode Control, Particle Swarm Optimisation

The design of a multi-input and multi-output controller for a coupled system like an active magnetic bearing is quite challenging. By decoupling the systems states simpler single input and single output controllers can be used. However, the AMB system still exhibits strong nonlinearities in the electromagnetic system the controller must handle. Thus, a second-order sliding mode controller is utilised to control the rigid rotor of the active magnetic bearing. The aim is to improve the stability and robustness of these systems by addressing common problems such as disturbances and nonlinearities like gyroscopic effects. Particle swarm optimisation is used to tune the control parameters to improve system performance. The effectiveness of the proposed controller is validated in simulation.

107 - Torque-to-weight: driving the next electrification wave

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Keywords: electrification, high-ratio gearboxes, hydraulics, heavy-duty machinery, aeronautics

1 Introduction

Electrification is a critical component of modern society, driving the development of sustainable energy solutions for transportation, residential, and commercial usages. The potential benefits of electrification include reduced greenhouse gas emissions, improved air quality, and enhanced energy efficiency. Moreover, the integration of renewable energy sources, such as solar and wind power, is further bolstering the transition to a more sustainable and greener electricity grid. Notably, the electrification of passenger vehicles is at the vanguard of this transformation, serving as a pioneering reference for the broader electrification movement.
However, heavy-duty machinery and aeronautic applications, among others, still face challenges in following this trend. The main reason behind this situation is that when actuators need to provide very high torques while being very lightweight, hydraulics provide a substantial advantage compared to purely electrical actuators [1].

2 Robotics and the importance of High-Ratio transmissions

Robotics is another area that shares this fundamental need of high torque-to-weight performance. To perform their task as automation devices with high flexibility, industrial robots combine an electric motor with a high-ratio gearbox in each of their typically six to seven joints. The use of a high-ratio gearbox allows robotics' engineers to avoid the limitation of the direct proportionality between torque and weight of electric motors. Interestingly, the need for high positioning accuracy in industrial robotics is a strong motivator for using electric motors without gearboxes (direct-drives). Yet, the inevitable large actuator weight that results from a direct-drive actuation strategy prevents this solution from being functional and explains why the practical totality of the current industrial robots use gearboxes in all their joints, with gear ratios that typically range from 40:1 to 120:1 [2, 3].

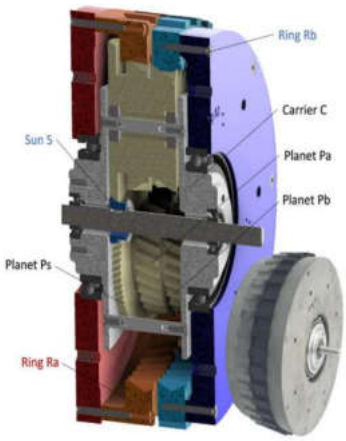

Figure 2 - High-ratio robotics gearbox [4]

The incipient arrival of modern, human-centric robotics, such as collaborative robots, exoskeletons, humanoids, and bionic prostheses, brings with it a need for even higher torque-to-weight performance. To mimic the extraordinary ability of the human body to deliver torque-to-weight in excess of 100Nm/kg, robotic engineers have explored during the last almost three decades pneumatic, hydraulic, and electrical actuators, together with other more exotic actuation principles. Although hydraulic-based actuation has probably delivered the most promising results in terms of human-like performance, for which the extraordinary abilities of the *Atlas* robot of Boston Dynamics provide probably the most notable example, solutions in this field converge progressively towards electric actuation. Most human-centric robots use today gearboxes with even higher gear ratios than their industrial counterparts, typically 100:1 or more. However, recent developments in torque-motors combined with the excellences of backdrivability for human-robot-interaction have led to the proliferation of quasi-direct-drive solutions with lower gear ratios (typically under 30:1) in human-centric robotics. Although these solutions can simplify human-robot-interaction, they are unavoidably linked to substantial higher robot weight, compromising safety and agility [5].

3 Applications for electrified systems

Replacing hydraulic systems with electrical systems offers several advantages. Electrical systems are generally cheaper than hydraulic systems when the required ancillary hydraulic equipment is included. Further, electrical systems offer excellent control capabilities, providing a very versatile solution to build highly capable systems. Electrical systems tend also to be more energy-efficient than hydraulic systems, resulting in lower operating costs and reduced environmental impact. Environmentally also, electrical systems are quieter, cleaner, and require less maintenance than hydraulic systems, which are prone to leaks and require frequent inspections, cleaning, and top-ups. Electrical systems are easier to scale and can be more easily integrated with other electrical systems, such as renewable energy sources. Finally, hydraulic systems bring additional risks linked to potential leakages of highly pressurized, poisonous and flammable fluids [6].

3.1 Heavy Duty Machinery Applications

Heavy-duty machinery applications, such as agricultural, construction, and material handling machinery, require high torques to move. The powertrain of these devices typically consists of large wheels or tracks moving at relatively moderate speeds. A potential lies in the replacement of their hydraulic or engine-based powertrains with a combination of a high-speed, lightweight electrical motor and a high-ratio gearbox.

Solutions involving in-wheel actuators are thinkable and would bring interesting functionalities for these machines, like torque vectoring.

These machines incorporate additional actuators to lift weight, drive harvesting heads, etc. Here again, torques tend to be very large while speeds are more moderate, opening the possibility to replace the current largely hydraulic solutions with an electric drive. An interesting potential here lies in the possibility to use the negative-work operations, like lowering a large load, to use the electric motor as a generator and thus recuperate a substantial part of the energy.

The main challenges for electrification of these machines lie in the rough environments that these devices tend to operate in, as well as the criticality of their availability. These are expensive machines that need to operate reliably during long hours to recover the large acquisition investment, and their non-availability when needed is typically linked to substantial losses in the large projects where they are used.

3.2 Aeronautics and Space Applications

Modern aircraft, helicopters, and launchers rely on multiple actuators that can be classified into primary flight systems, secondary flight systems, landing gears, and auxiliary systems. Primary flight systems control aircraft trajectory and usually consist of control surfaces for steering roll (ailerons), yaw (rudder), and pitch (elevators). In spacecraft, they usually consist of thrust vectoring devices. Secondary flight systems control the aerodynamic configuration during particular flight phases, such as lift improvement during takeoff (flaps), landing (spoilers), etc. Landing gears involve actuators to open/close the landing gear door and extend/retract the gear itself, and to brake. Finally, auxiliary systems involve actuators to power some utilities like cargo and passenger doors [1].

Although the replacement of hydraulic actuators with electrical actuators has some potential benefits in terms of efficiency and space- and weight reduction, and the incorporation of more advanced force-control strategies, the extreme operating conditions of these devices pose significant challenges. These conditions involve very low temperatures and low pressure to vacuum conditions, which render lubrication a substantial challenge. Further, the risk of gearbox jamming is often too high for the deployment of electric actuators in primary flight systems. Due to the high accelerations involved, shock and vibration requirements are also substantial challenges in these applications, while challenges posed by the required positioning accuracy and bandwidth tend to be moderate compared to other applications [1,6].

4 Conclusion

Electrification of heavy-duty applications has proven to be more challenging than that of passenger vehicles due to the limitations of electric actuators to provide high torque-to-weight ratios to replace hydraulic-based actuators. However, the experience accumulated in robotics during the last few decades indicates that the availability of a compact high-ratio gearbox that can be combined with a lightweight electric motor is pivotal in this endeavor. Despite the extreme operating conditions of heavy-duty and aeronautic devices, the potential for the deployment of electric motors combined with high-ratio gearboxes is substantial and justifies dedicating resources to identifying promising use cases and exploring solutions for these challenges. This is the main objective of the recently launched ALOHA project, which brings together the expertise of

the Vrije Universiteit Brussel with high-ratio robotic gearboxes, the expertise of Flanders Make in the design and validation of gearboxes for high-power applications, and its connection with the field experience of a large pool of industrial partners in the Flanders region.

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207 - High Order CBFs for the Safety-critical Control of Coaxial Octorotor UAVs

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Owing to their versatile maneuvering capabilities, uncrewed aerial vehicles (UAVs) show great promise for applications in agriculture, search & rescue, and surveillance. Coaxial Octorotor UAVs (COUAVs) have eight rotors arranged on four arms, with the end of each arm containing a pair of counter-rotating propellers. The configuration not only enhances the UAVs resistance to disturbances, but also provides almost double the overall thrust compared to a quadrotor of similar dimensions, making it well-suited for heavy-lift applications. Ensuring the safety of COUAV deployment across diverse environments is a crucial challenge, which demands careful consideration. The inherent underactuation and instability of COUAVs add an additional layer of complexity to the generation of secure trajectories.

Control Barrier Functions (CBFs), which can be used to guarantee the operational safety of robots, have been found to be useful in numerous applications. However, the basic CBF formulation is unsuitable for nonlinear systems with high-order relative degree constraints. One of the approaches developed to deal with this problem is the use of High Order CBFs (HOCBFs).

We propose a super-twisting sliding mode controller (SMC) combined with a novel HOCBF-based quadratic programming (QP) controller to guarantee safety. The main contributions of this research are:

1) A novel HOCBF-based QP approach is proposed to provide a safe trajectory tracking controller for COUAV.
2) A MIMO super-twisting SMC is considered as the nominal controller that takes into account variable interactions, a critical factor for addressing highly coupled states within COUAV.
3) To address the inherent underactuation issue in COUAV dynamics, the flight control system design integrates a hierarchical control structure employing an inner-outer loop framework.

The proposed method is illustrated through two simulation scenarios that takes into account the dynamic characteristics of a heavy-lift COUAV: The first scenario involves the presence of three static obstacles, while the second scenario considers three moving obstacles. The unsafe regions are spheres of radius 2 m centered at the center of each obstacle. In both simulation cases, the COUAV is able to accurately track the reference trajectory, while successfully avoiding collisions with the static and the moving obstacles.

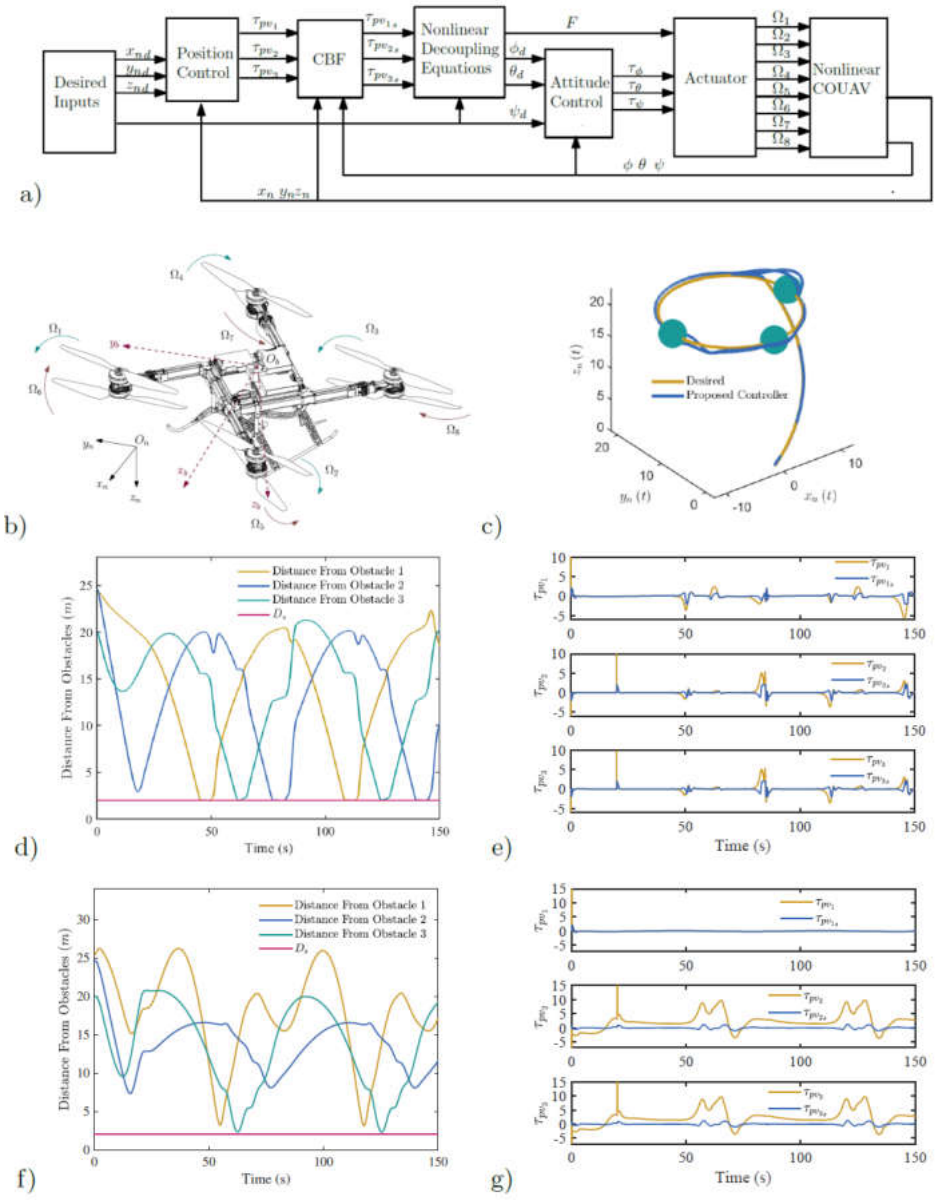

Fig. 1: a) Structure of controller. b) FlyingBasket COUAV. c) Trajectory with three static obstacles (cyan spheres). d) Distance from each static obstacle. e) Control inputs for static obstacle case. f) Distance from each moving obstacle. g) Control inputs for moving obstacles case.

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307 - Research Perspectives for the Near- and Far-future Development of Civil Aviation

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Keywords: air transport development, aero-engine development.

Abstract. Demands for reduced environmental impact of air transport drive innovation and improvement in civil aviation. Beyond 2024, new efforts are required to improve the overall flight efficiency and fuel burn to meet the Advisory Council for Aeronautics Research in Europe (ACARE) goals for the years 2035 and 2050. The year 2050 targets aim for a 75% reduction in CO2 emissions, a 90% reduction in NOx emissions and a 65% reduction of the perceived noise relative to engine and aircraft performance of the year 2000. To achieve these goals, the successful execution of the European Clean Aviation programme is critical. According to the Vision for Clean Aviation [1] the European aeronautics sector is committed to work towards fully climate-neutral aviation by 2050. This talk will overview research perspectives for the near- and far-future development of civil aviation particularly emphasizing research work at Chalmers University of Technology.

5 Perspectives for the near future (10-15 years from now)

The expectations are 85-90% reduced emissions for a regional and short-medium range aircraft. The technology development is towards highly efficient aircraft configuration with reduced weight and optimized aerodynamics, electric and distributed propulsion coupled with ultra-efficient gas turbine engines and ultra-high bypass propulsion system, possibly open rotor. A fully electric small aircraft and new short-distance mobility are expected. Increased use of sustainable aviation fuels (SAFs), green aircraft operations and infrastructures, green aircraft regulations. Some characteristic examples of these technologies are shown in Figures 1 and 2. Figure 1 depicts an electrical 30-sits regional aircraft developed by Heart Aerospace, Sweden. Heart Aerospace is a company with Chalmers' roots and with a long history of collaboration with Chalmers since the company's foundation. Figure 2 is an illustration for near- and far-future vision aircraft concepts developed in a 140 M€ Clean Aviation project SWITCH coordinated by MTU Aero Engines in which Chalmers University participates.

6 Perspectives for 2050 and beyond

The expectations for 2050 are fully climate-neutral aircraft operations and infrastructures and climate-neutral aircraft regulations. The key technologies are hyper-efficient aircraft with the minimum weight and maximum aerodynamic performance driven by fully decarbonised energy sources, with zero net emission, such as liquid hydrogen, electro fuels, batteries and fuel cells. Figures 2 and 3 illustrate some of these technologies. The hybrid Water-Enhanced Turbofan (hybrid WET) uses an advanced WET technology with hybridization to improve energy efficiency by 25% and reduce climate impact by 75% (using net zero-CO2 sustainable aviation fuel, 50% with conventional Jet-A kerosene) compared to a state-of-the-art engine. An innovative concept of the Composite Cycle Engine (CCE) shown in Fig. 3 from a coordinated by Chalmers project MINIMAL combines a gas turbine and a piston engine. This increases thermal efficiency due to the extremely high peak pressure and temperature within the cylinders and provides a two-digit improvement in fuel burn relative to state-of-the art aeroengines. The talk with discuss these and other innovative concepts contributing towards the European Green Deal's goal of climate neutrality by 2050**.**

References

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Fig. 3. A visionary image of ES-30 electrical aircraft developed by Heart Aerospace, Sweden https://heartaerospace.com

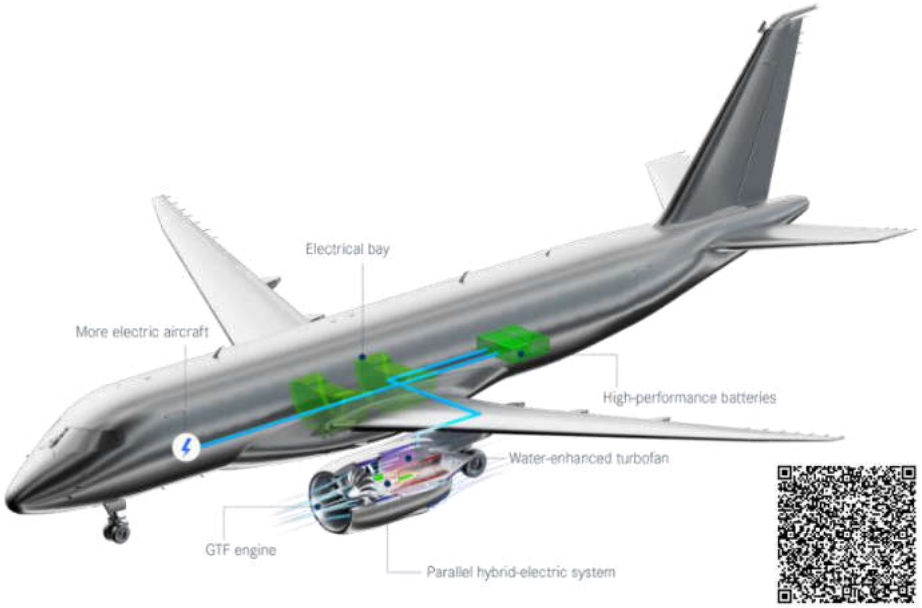

Fig. 2. The Sustainable Water-Injecting Turbofan Comprising Hybrid-Electrics (SWITCH) project aims to improve fuel efficiency on narrowbody airliners by 25 percent and cut emissions. The Water Enhanced Turbofan (WET) concept recovers water vapor from the engine exhaust and re-injects it into the combustion chamber of the turbofan. Image: MTU Aero Engines. https://www.mtu.de/newsroom/press/press-archive/press-archive-detail/clean-aviation-switch-project-to-advance-hybrid-electric-and-water-enhanced-turbofan-technologies

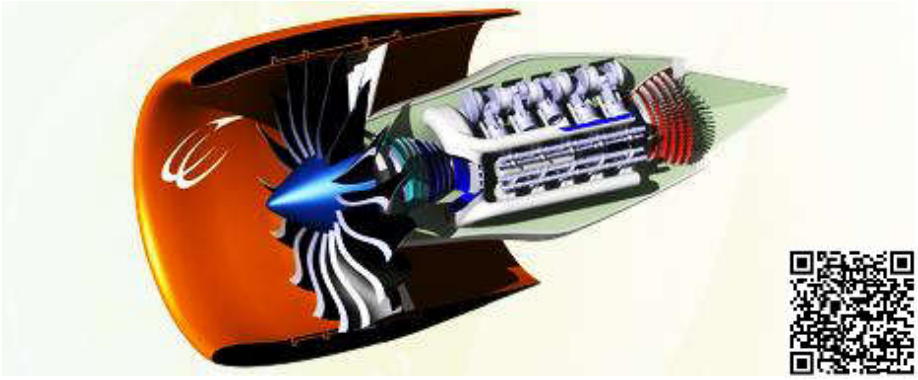

Fig. 3. A conceptual design of composite cycle engine proposed in a Horizon Europe project MINIMAL coordinated by Chalmers. https://www.minimal-aviation.eu/technologies

108 - Finite element investigation of torque ripple in roller-cycloidal contact: examining gear ratio, mesh density, and transmitted power dependencies

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Keywords: FEM, FEA, Cycloidal Drive, Dynamic, high-power density

The low backlash of cycloidal gearboxes is undoubtedly a distinctive feature. However, due to their architecture, cycloidal drives exhibit torque oscillations, i.e. Torque Ripple (TR), caused by variations in system stiffness as con-tact points change over time. Such oscillations can be critical in position control applications. One of the most common approaches to analyze torque ripple, namely finite element analysis, is exploited and discussed in this paper. Specifically, the aim is to investigate how modeling parameters such as mesh density, in different geometries and operating torques, impact torque ripple estimation. Preliminary results from 12 simulations, conducted at two gear ratios, two levels of transmissible power, and three mesh densities (coarse, medium, fine), demonstrate that with an equal number of elements per cycloidal disk lobe, models with smaller GR exhibit larger TR. It is observed that changes in Mesh density significantly affect TR, without a corresponding significant change in maximum stress levels. Additionally, lower applied torques result in higher TR, though this effect diminishes with denser meshes. These findings highlight the critical need for thorough mesh sensitivity analysis in TR studies and the necessity to establish a contact zone discretization approach that is independent of GR, to accurately assess and mitigate TR in cycloidal drives.

208 - Design and development of an autonomous surface vehicle for supporting underwater navigation

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Keywords: autonomous surface vehicle, marine robotics, robot design, cooperative acoustic navigation

This work details the conceptualization and development of an Autonomous Surface Vehicle (ASV) designed for supporting underwater navigation. The ASV, which is named MARINA (Marine Autonomous Robot for Intelligent Networking Operations), was developed at the Robotics, Automation and Autonomous Systems Laboratory of the Department of Information Engineering of the University of Pisa. First, the paper outlines the main considerations that led to the conceptualization of the prototype. Then, the main features in terms of hardware and software, which have been adopted for the realization of the desired marine robot, are summarized. Finally, preliminary results obtained during a preliminary experimental campaign in a lake environment are proposed.

308 - The role of advanced experimental methods in aerodynamic evaluation of state-of-the-art turbofan engine components

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1 Introduction

The integration of innovative technologies into aircraft engines is a critical and meticulous process, vital for ensuring exceptional performance, reliability, and safety. This process involves nine technology readiness levels, ranging from initial research on basic principles to the final implementation of the technology in aircraft engines. One of the most crucial stages of this process is the testing and validation of these technologies in a controlled laboratory setting. Therefore, continuous improvement of engine components requires ongoing experimental investigations conducted under engine-relevant conditions. In support of this, Chalmers University of Technology provides two state-of-the-art facilities dedicated to testing realistic internal turbofan engine structures, such as turbine rear structures (TRS) and intermediate compressor ducts, shown in Figure 1.

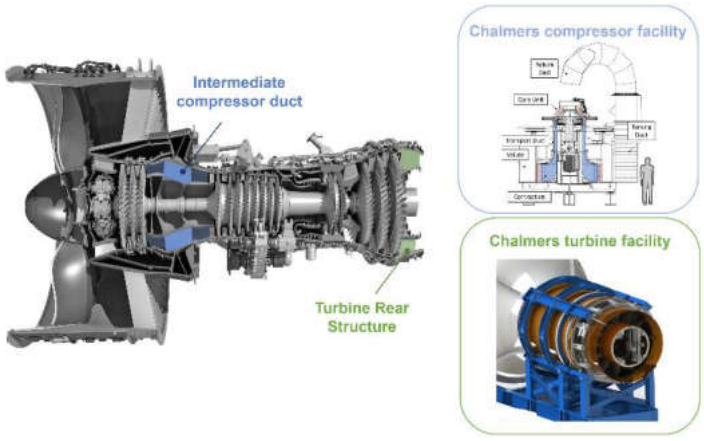

Fig. 4. Schematic of a turbofan engine with highlighted internal engine structures, paired with corresponding test facilities for aerodynamic evaluation.

This paper summarizes the experimental findings obtained from the turbine facility over recent years, illustrating the effectiveness of an experimental multimethod

approach in the field of turbomachinery research. The primary objective of this work is to highlight the advantages of using different measurement techniques that are currently applied in aerodynamic evaluation of state-of-the-art TRS designs.

2 Experimental setup and results

For the experimental investigation of the TRS flow, a multimethod approach was applied and involved an array of advanced measurement techniques. This included the use of multi-hole pressure probes, static pressure taps, the oil-film method, infrared (IR) thermography, hot-wire anemometry and PIV techniques. The measurements were performed in an annular turbine facility with shrouded low-pressure turbine (LPT) stator-rotor stage located upstream TRS stator. Tests were carried out under Reynolds number of 235,000 and flow coefficient typical for engine cruise condition.

The main results of these experimental investigations are depicted in Figure 2. This figure provides a schematic of the TRS flow, highlighting the results obtained from each measurement technique.

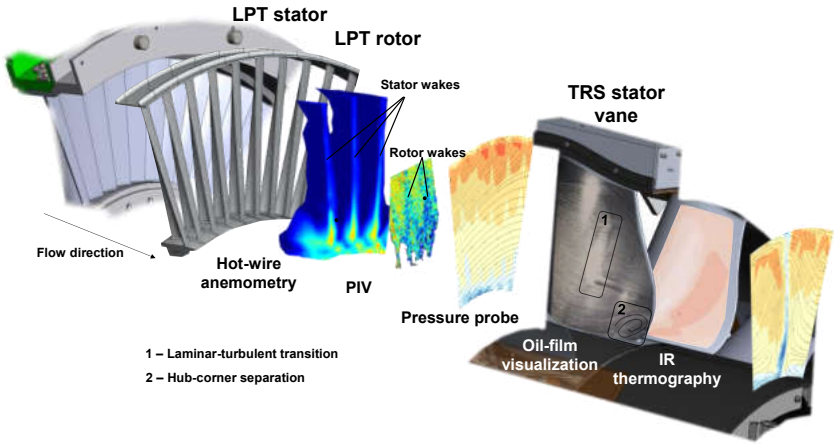

Fig. 5. Schematic of TRS flow illustrated by hot-wire anemometry and PIV results, total pressure contours, oil-film visualization and IR thermography patterns.

The results from hot-wire anemometry and PIV measurements provided time-resolved and instantaneous velocity field data, essential for future high-fidelity CFD simulations. These techniques were instrumental in capturing the unsteady flow phenomena including the structure and interaction of the LPT rotor and stator wakes. Furthermore, pressure measurement results offered time-averaged data, such as swirl angle, total, and static pressure distributions. The extensive dataset facilitates an accurate evaluation of turning performance and pressure losses, which are crucial aspects in the comprehensive assessment of aerodynamic efficiency. In addition, the experimental campaign involved oil-film visualization, effectively identifying local flow separations and loss-generating structures near the wall. This qualitative data

contributes to a better understanding of the flow phenomena in the close proximity of the wall and the origin of additional pressure losses. Lastly, the measurements utilizing IR thermography yielded surface heat transfer data. This technique not only provided critical insights into the thermal characteristics but also proved to be highly effective in identifying the laminar-turbulent transition.

109 - Loads in the planetary-pinion gear with modification of the tooth profile and eccentricity of the satellites

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Keywords: cycloidal reducer, contact forces, eccentricity, contact zone, coefficient of shortening

In k-h-v planetary cycloidal drives, motion is transmitted to many rollers and teeth of the cycloidal disc. The number of factors affecting the load distribution in the engagement is very large, including modification of tooth profiles and inaccuracies in the manufacture of cycloidal gears. The forces arising from engagement load the satellite supports. The article presents the results of research aimed at creation a mathematical calculation model that provides more accurate accounting of loads in cycloidal engagement. It is based on an analytical solution to the problem of the effect of gaps in the engagement of the planetary gear and the eccentricity of the satellite on the load distribution in the engagement and the loading of the satellite support. A characteristic of the uneven load of the satellite support is proposed. The MathCad package was used in the computer experiment. It is shown that the operation of the cycloidal engagement is accompanied by a continuous change in the forces acting in the engagement.

209 - Local path-planning optimisation for an industrial Autonomous Mobile Robot via dynamic obstacle detection

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Keywords: Autonomous Mobile Robots, Robot Navigation, Local Path- Planning, Dynamic Obstacles

Over the last decade, there has been a substantial surge in the demand for Autonomous Mobile Robots (AMRs) owing to their proficiency in navigating complex environments without the use of physical or electromechanical guidance devices. In particular, the exploration of obstacle avoidance holds paramount importance in AMR research, particularly as these robots are intended to function in settings with the presence of humans, vehicles, or other robots, necessitating the safe evasion of both stationary and moving obstacles.

Within this context, this paper presents a solution for navigating in dynamic environments that can be easily integrated into the current ROS2 Navigation Stack (Nav2). The proposed solution is based on a Laser Imaging Detection and Ranging (LiDAR) sensor-based system, which allows for the detection of dynamic obstacles and estimating their velocities using a linear Kalman filter. The obtained information was integrated into the navigation system and the proposed solution was then validated through a campaign of simulation tests on an AMR prototype developed by HSG Engineering Srl. Simulations showed that this architecture guarantees safer navigation and represents a solid starting point for developing the robot's navigation for industrial use.

309 - The use of Infrared thermography in Advanced Experimental Investigations of State-of-the-art Turbofan Engine Components.

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Infrared thermography (IRT) is a non-destructive technique widely used across various disciplines. It is valued for its high sensitivity and non-contact nature, enabling the capture of surface temperatures and heat transfer on complex geometries. Advancements in sensor technology, increased processing power, and cost reductions have transformed IRT into a significant, accurate, and versatile tool. However, its use requires arduous calibration, data processing, and uncertainty analysis to ensure result reliability.

IRT has emerged as a potent tool in the realm of aerothermal measurements. It is especially beneficial for inverse heat transfer studies and the application of machine learning algorithms. How- ever, to guarantee accurate outcomes, the implementation and analysis of IRT must be conducted with utmost precision.

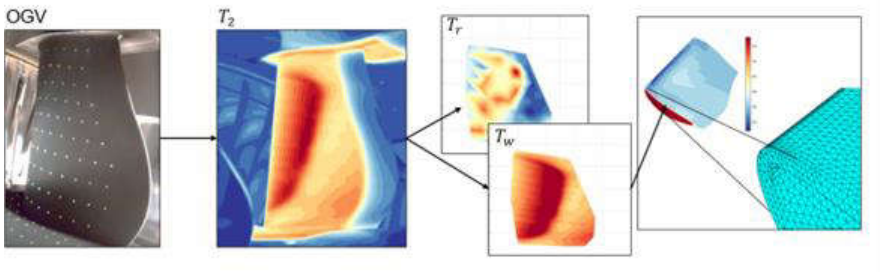

Fig. 1. Example of an implementation of heat transfer measurement in a turbine rear structure using infrared-thermography, water channel heating on an outlet guide vane (OGV) manufactured in SLA.

This work presents the development and application of infrared thermography at Chalmers' Fluid and Thermal Sciences laboratory to investigate the aerothermal performance of jet engine structures, such as the turbine rear structure (TRS) and the intermediate compressor duct (ICD).

Experimental Setup and Results

IRT investigations at Chalmers were conducted in two facilities, the low-pressure compressor and turbine facility, both operating at speeds under 100 m/s and investigating large engine structures. Both setups explore flow transitions and separations, allowing interchangeable instrumentation.

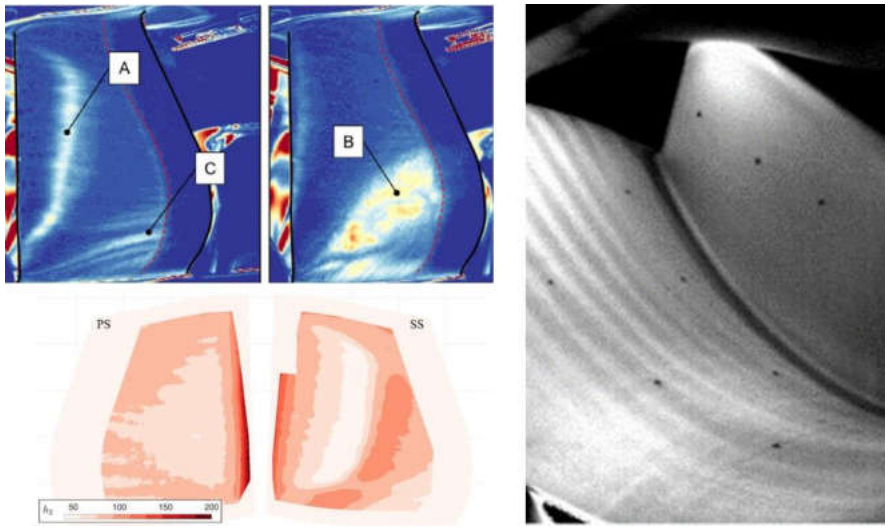

Fig. 2. Three different user cases of the IRT inside the TRS and ICD test facilities. The steady state heat transfer measurement in the TRS. Unsteady flow feature investigation on TRS and the inverse heat transfer method in the ICD.

The study explores three primary aerothermal investigation methods. One is a steady-state approach where internal water channels maintain a steady heat flux, with heat flux determined through surface temperature distribution. Radiative heat transfer using reflective marker array (RMA) is used to isolate convective heat flux from radiation. This enables heat transfer analysis where internal water channels are feasible. Results from the methods is depicted in Fig. 1 and the lower left corner of Fig. 2. This dataset also facilitates the detection of changes in surface friction via Reynolds analogy, identifying transition locations (A), corner vortex (C), and separations (B) in Fig. 2. Despite effectively mitigating most significant uncertainties in steady-state heat transfer measurements, variations in thermal conductivity remain a challenge, particularly due to ageing or changes in ambient conditions.

Moreover, alternative methods were devised for scenarios where achieving internal steady heat flux was impractical due to thin walls or high curvature. In such cases, periodic external heat sources were applied via radiation on the external surface, with the heat transfer coefficient deduced from the resulting thermal response. This approach

offers the advantage of in-situ calibration of thermal conductivity through the lock-in method, employing step increases in convective heat flux.

Experiments conducted at Chalmers' Fluid and Thermal Sciences Laboratory yielded com- prehensive database that provides invaluable insights into the flow field within these components and serves as critical validation for numerical simulations. According to the author, perhaps most importantly, these studies culminate in detailed guidelines for conducting accurate aerothermal studies utilizing IRT.

110 - The influence of thermal stresses on the load distribution in cycloidal reducers

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Keywords: Cycloidal Reducer, Contact Forces, Thermal Analysis

High precision reducers (HPRs) are being increasingly used in modern industrial systems, especially in industrial robots. That is way the number of installed cycloidal reducers (the most commonly used HPRs) is increasing year after year. In order to design a cycloidal reducer, to determine its efficiency and distribution of stresses and deformations, it is necessary to know the intensity and character of the load. A number of papers dealing with this subject have been published. They analyze the influence of different parameters on the load distribution in cycloidal reducers, such as clearances, modification of the cycloidal disc tooth profile, etc. This paper analyses the influence of thermal stresses (which occur during operation) on distribution of contact forces between the central rollers and the cycloidal disc teeth. This analysis is very important because high operating temperatures affect the size of clearances between the elements that transfer the load and, thus, the number of elements in contact. Intensities of thermal sources were determined analytically (Matlab), while the contact forces were determined numerically using the Ansys software. The obtained results show that the influence of temperature on distribution of contact forces cannot be ignored, especially with frequent starts, stops and considerate overloads.

210 - Towards Robotic Pose Graph Estimation with Tree Landmarks in Perennial Orchards

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1 Introduction

The transition toward regenerative agriculture requires robotics platforms that manage perennial crops and can navigate through them, despite the challenges they present. Compared to annual crops, orchards offer order and certainty to localization by rows of stems planted at regular intervals. Such landmarks can be exploited for 10 cm accurate localization without GNSS [1].

The main contribution of this work is the definition of a pose estimation method based on factor graphs and georeferenced fiducial markers which act as proxy for segmented trees which will used in future work. The method is agnostic towards the type of odometry provided to the system. The method was evaluated on data collected in a mockup orchard.

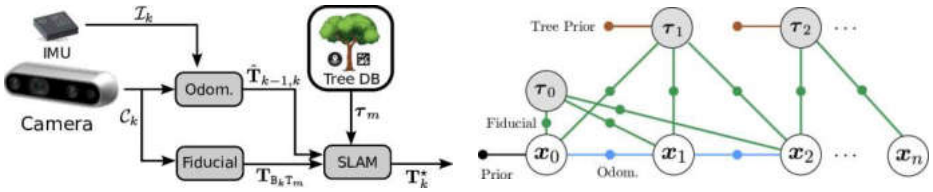
2. Problem Statement

We aim to recover the absolute poses $T_k = T_{WB}(t_k) \in SE(3)$ of a mobile robot at each time step t_k given: a set of IMU measurements I; and camera measurements C. We further assume that a set of M known landmark locations $\tau_m \in \mathbb{R}^3$ are available. For our application, these are represented by orchard trees with known GNSS coordinates.

3. Method Description

Our localization algorithm is illustrated in Fig. 1a. First, an odometry algorithm fuses the IMU data and the camera images (and, optionally, GNSS) to acquire a constant stream of smooth but drifting relative pose estimates of the robot $\hat{T}_{k-1,k}$. At the same time, a fiducial detector module reports the relative transformation from the current base frame B_k and the absolute coordinates of the landmark τ_m. Then, the SLAM module will retrieve from a database the GNSS fixes of the detected tree landmarks, convert

them into Cartesian coordinates, and find the optimal pose of the robot at the current time $\boldsymbol{T}_k^\star$.



(a) System Overview (b) Factor graph for the SLAM

Fig. 1: System Overview. IMU and camera signals are fused by a VIO system, while a fiducial detector module computes the relative position between a tree and the robot. The SLAM module will fuse these two pieces of information to compute the optimal absolute pose of the robot $T_k^\star$.

3.1 Method Description

We use the implementation from Cao et al. [2], which is designed to fuse both raw GNSS and VIO odometry tightly. However, under extremely degraded GNSS, it degrades to the monocular VIO system from [3].

The detection of the tree-mounted fiducials is performed using the AprilTag library [4].

3.2 SLAM module

Given the relative poses from the odometry module and relative 3D poses between the robot's base and each detected tree landmark, the SLAM problem shown in Fig. 1b is formulated as the minimization of a cost function with four residuals: prior (black), odometry (blue), fiducial (green), and tree prior (brown). The tree prior accounts for uncertainty on the known tree locations and enforces staticness on the trees.

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310 - Helicopter drive system featuring additive-manufactured components

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Keywords: Additive manufacturing, Topology optimization, Helicopter Gearbox

Additive manufacturing constitutes an exciting avenue in the design of aerospace components, due to the archetypal capabilities of realizing complex geometries allowing for weight reduction. Although several attempts have been carried out to 3D print aerospace components, the number of parts installed on helicopter gearboxes is still limited, mainly due to their criticality. This paper unveils the design process leading to the manufacturing of two prototypical parts installed in the input module of a tilt-rotor drive system (Next Generation Civil Tilt-Rotor – NGCTR – Technology Demonstrator), mainly an auxiliary lubrication tank and a pump case. Specifically, this work illustrates the design constraints which have encouraged the adoption of a pioneering manufacturing process in the domain of aeronautic components. In addition, the approach employed to match these imposed boundary conditions is discussed, alongside with the final geometries resulting from an optimization process.

211 - A control barrier function based approach for close inspection with USVs

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Safety-critical control using control barrier functions (CBFs) is a relatively recent approach that permits an automatically controlled system to fully-utilize the safe operating conditions available, while guaranteeing the stable avoidance of unsafe conditions. When desired, the use of a CBF-based safety-critical controller can permit a system to operate at the boundary between safe and unsafe, ensuring that the system remains on the safe-side of that boundary. For applications that require an uncrewed surface vessel (USV) to perform the closest possible safe approach to an object of interest, CBF-based safety-critical control techniques can be very useful.

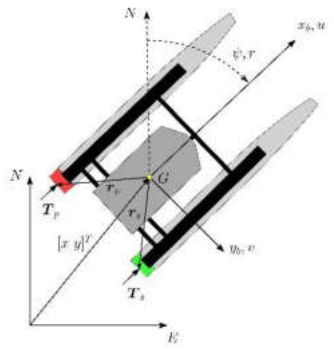
A significant advantage of the use of CBFs is that they permit the safety of a system to be incorporated in a flexible, modular, way because the safety objective can be solved separately from the control objective, while at the same time they are reactive, so that knowledge of the system's high-level (deliberative) motion plan is not required.

Here we propose a computationally lightweight controller for USV survey, inspection and intervention. A safe set of states is defined for trajectory tracking in the presence of moving targets, together with a mathematical definition of the CBFs and an analytical solution for an optimal safety critical control input.

The controller guarantees a minimum safe standoff distance to an inspection target using safety-critical control to ensure that a safe minimum standoff distance is maintained throughout the inspection. The controller is designed to produce dynamically feasible control inputs, which take the nonholonomic dynamic (acceleration) motion constraints of USVs into account.

Illustrative simulations of a USV approaching both stationary and moving targets are used to demonstrate implementation of the method. The simulation results show that when a desired trajectory is intentionally planned so that it passes through the unsafe set surrounding a stationary or moving target, the USV will approach the target and move along the boundary of the unsafe set, before passing the target and returning to follow the parts of the desired trajectory outside of the unsafe area.

The performance of the proposed controller is compared with that of a nonlinear model predictive controller (MPC) in simulation. While the tracking error of the proposed controller is higher than that of an MPC, it requires lower computational resources, suggesting it is a good candidate for use on small USVs with low computational power.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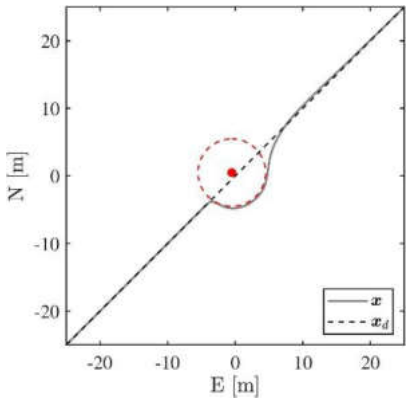
(a)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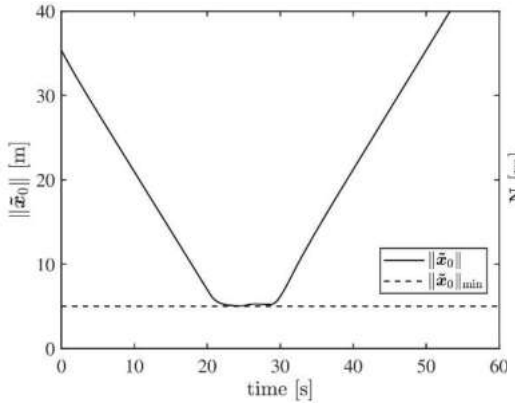
$\|\tilde{\boldsymbol{x}}_0\|$ [m]
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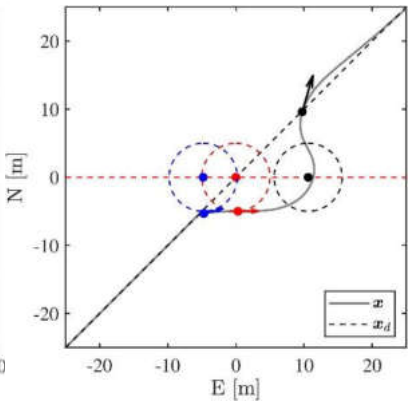
(c)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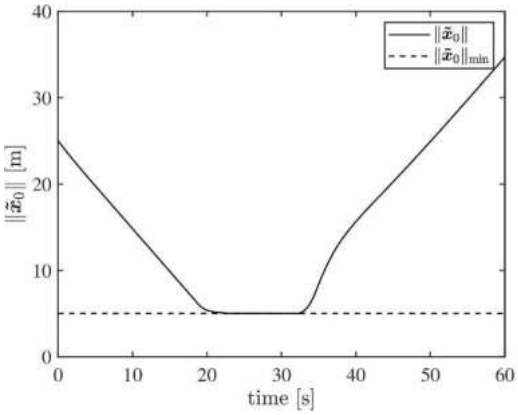
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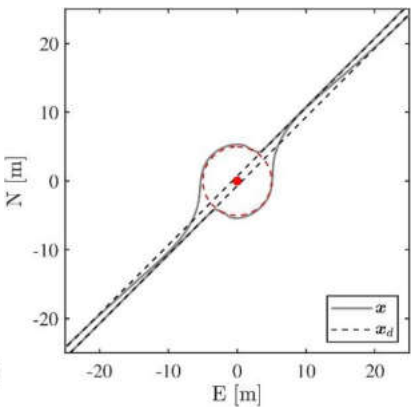
N [m]
E [m]
$\boldsymbol{x}$
$\boldsymbol{x}_d$

(f)

Fig. 1: a) The underactuated USV. b) Case A: Desired x_d and actual x trajectories of the USV as it moves around a stationary target, which is indicated by the red dot at $x_0 = (0.5, -0.5)$. c) Case A: Distance between USV and target $\| \tilde{x}_0 \|$ as a function of time. d) Case B: Desired x_d and actual x trajectories of the USV as it approaches a moving target, whose trajectory x_0 intersects the desired trajectory of the USV at time t = 25 s. e) Case B: Distance between USV and target $\| \tilde{x}_0 \|$ as a function of time. f) A 360◦ inspection trajectory. In subfigures b), d) and f), the boundary of the unsafe set $\| \tilde{x}_0 \|_{min}$ is designated by a dashed circle.

311 - On and Offboard Technologies for Autonomous UAMs in Urban Emergency Response Roles

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Keywords: UAM, Vertiports, Autonomous Flight, Airspace Integration.

Abstract. This paper explores the integration of Urban Air Mobility (UAM) into emergency medical services through the Air Mobility Emergency System (AMES) project, initiated by Chalmers University of Technology, including advanced navigation, anti-collision systems, and the critical shift towards high-level autonomy with provisions for human oversight. Addressing the challenges of noise and visual pollution, public perception, collision avoidance, and cybersecurity, the paper proposes a holistic approach to developing a comprehensive regulatory framework. This framework aims to enhance the safety, efficiency, and public acceptance of UAM in emergency services, advocating for its seamless integration into urban environments. The AMES project exemplifies a pioneering effort to leverage autonomous aerial vehicles for improving emergency medical responses, underscoring the balance between innovation and addressing societal concerns.

1 Introduction

Given the current trajectory of urbanization, it is projected that by 2050, as much as 80% of the populations in Europe and North America might reside in urban areas [1]. This demographic trend demands an expansion in transportation and service offerings, potentially leading to increased congestion within the already saturated surface road networks. From 2000 to 2019, traffic volume witnessed a 31% increase [2], pointing towards an imminent crisis in urban mobility and service delivery, particularly in medium and large cities. Autonomous Urban Air mobility presents itself as a solution to decongestion by making use of the urban aerial space currently not in use. This task conveys the necessity to ensure safety for both users, non-users, and surrounding vehicles. Due the multitude of players and possible scenarios involved, this is a complex problem to solve, a “Grand Challenge” as pictured by NASA [3], requiring new sets of investigations.

In a similar fashion, Chalmers University of Technology has initiated a project to create a testing platform where different roles and situations can be researched. Current

automotive technologies are emerging as strong candidates to help in the achievement of a fluid circulation of autonomous aerial vehicles. However, there is a need of tuning, upgrading, and testing of such technologies before they can be considered on-board equipment. AMES project targets precisely this goal, aiming to provide a platform capable to test onboard and offboard (vertiports) critical systems as well as the interaction with existing aerial systems and its compliance with current and future regulations.

Among others, the prototype aims to support research in the following fields:

- Complex VTOL propulsion systems
- Fly-By-Wire electric pitch control
- Radar, Lidar and Cameras interaction
- Situational self-awareness
- Urban navigation system.
- Communication with manned aerial systems

Figure 1: Initial conceptual design of the AMES prototype. (Renderings by BOID AB).

Figure 1 shows the first design iteration for the Air Mobility Emergency System (AMES) test platform. This iteration did not pay special attention to the rotors (due in 2nd design) but highlights the same internal dimensions than the AW169 medical helicopter cabin (excluding pilot).

The decision to model the prototype as an air ambulance was based on the expectation of quicker societal acceptance for such vehicles, attributed to the essential nature of their service and the fewer units required relative to autonomous aerial taxis. This choice aligns with our objective to benefit healthcare needs in a future highly populated society through advanced research in air mobility vehicles and vertiports.

It is expected that the AMES prototype will start assembly by the end of 2024, followed by a 9 month testing phase that will culminate with a small flight display at the end of 2025 or beginning of 2026.

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112 - Multibody Simulation of Gearbox Dynamics Using 3D Contact Modeling and Measured Tooth Geometries

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Keywords: Multibody Dynamics, Polygonial Contact Model, Measured Tooth Geometry, Gearbox

Abstract. The ongoing transition towards electromobility and the consequent absence of combustion engine noise have drawn attention to gear noise reduction. To analyze and optimize the NVH-characteristics of a gearbox numerically, high-quality excitation data is essential. The primary source of excitation is the force generated by the contact of meshing teeth, which are transmitted to the housing. The forthcoming paper will show a method for determining these excitation data for a spur gear transmission under consideration of measured tooth geometries.

1 Preview

In the upcoming work, a multibody simulation model for a spur gear transmission will be presented. This model will be able to generate load data for a subsequent NVH (Noise, Vibration, Harshness) analysis. Gears will be treated as rigid and shafts as flexible bodies. In addition, the actual gear geometry is taken into account. The model will then enable a parametric study to investigate how imperfections in the tooth geometry and shaft misalignment affect the excitation of the housing.

1.1 Contact Algorithm

The gear contact forces are evaluated by the polygonal contact model (PCM), a contact algorithm for multibody dynamics which is based on polygonal surfaces [1]. One can think of the surfaces polygonals as they are each connected with an elastic spring. In case of a contact the k^{th} spring force F_k is calculated by:

$$F_k = (c_l \cdot u_{nk} + d_l \cdot \dot{u}_{nk}) \cdot A_k \tag{1}$$

where c_l is a stiffness and d_l a damping parameter, A_k the area of the polygon, u_{nk} is the penetration depth and $\dot{u}_{nk}$ its derivative. The contact algorithm has options to

prevent discontinuous and tensile forces resulting from the damping component. Fig. 1 shows a force distribution of meshing gears.

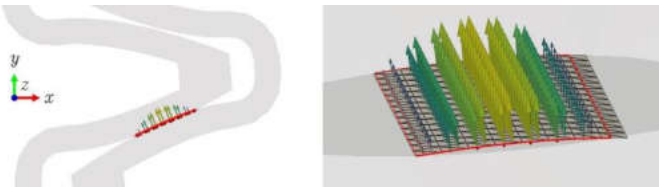

Fig. 1. Visualisation of contact forces

1.2 Contact Algorithm

The contact parameters cl and dl are identified using a test bench. The test bench consists of a stationary and a rotatably mounted gear with defined backlash. The rotatably mounted gear has a flattened spot (Fig. 2 left), where it is hit with an impact-hammer. At the same position the occurring velocity is measured using a laser vibrometer. This gives a timeseries of the force $f(t)$ and the velocity $v_{meas}(t)$. On the other hand, the force is applied to a simulation model of the test bench in order to calculate $v_{sim}(t)$. The contact parameters are then acquired by minimizing the quadratic difference of $v_{meas}(t)$ and $v_{sim}(t)$ by the Nelder-Mead Simplex Method.

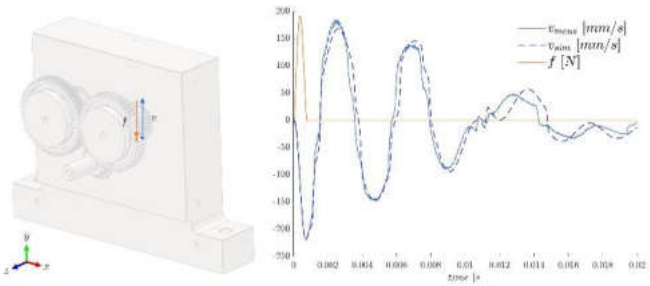

Fig. 2. Test bench for parameter identification

References

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212 - Development of a mechanical device to harvest energy from marine waves

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Keywords: wave's energy; renewable energy; mechanism; motion transformation.

1 Extended Abstract

One of the most promising renewable energy sources is the seas and oceans waves' motion. The main issue to harvest energy from waves is to transform the motion (oscillating motion) into a rotating motion, in order to be able to put the electricity generator in rotation. In the last years several devices have been developed to harvest energy form the seas, in general they focus the attention on the way to get energy from waves using different types of floater and ways to fix it. However, the transformation of floater motion in kinetic energy suitable for energy generation is obtained by "standard" systems not designed ad-hoc; the most of them consist in hydraulic systems, which show many issues, among the others, complexity and the risk of marine pollution because of the presence of oil.

In this work, a novel mechanism allowing the transformation of wave motion (alternative motion) into unidirectional rotating motion is presented. The mechanism faces the following issues: direct transformation of wave's motion in rotating unidirectional motion, absence of oil lubricant, higher efficiency (compared to already used systems), reliability.

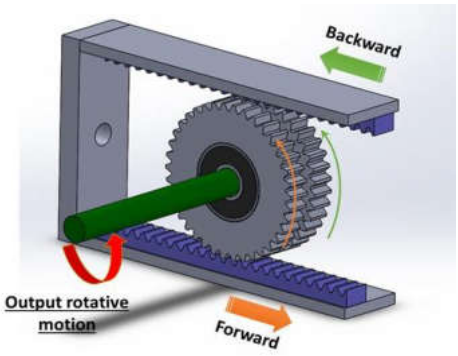

Fig. 6. Working principle of the Motion Transformation Device.

The Motion Transformation Device MTD, consists in a kinematic chain composed of gear rack system to transform linear motion into rotating motion and a series of free wheels used ad mechanical diode, to make the rotation motion continuous and unidirectional. A general schematic example of the device is shown in Fig 1.

In this work, the kinematic and dynamic models of the device have been developed allowing to investigate its performance.

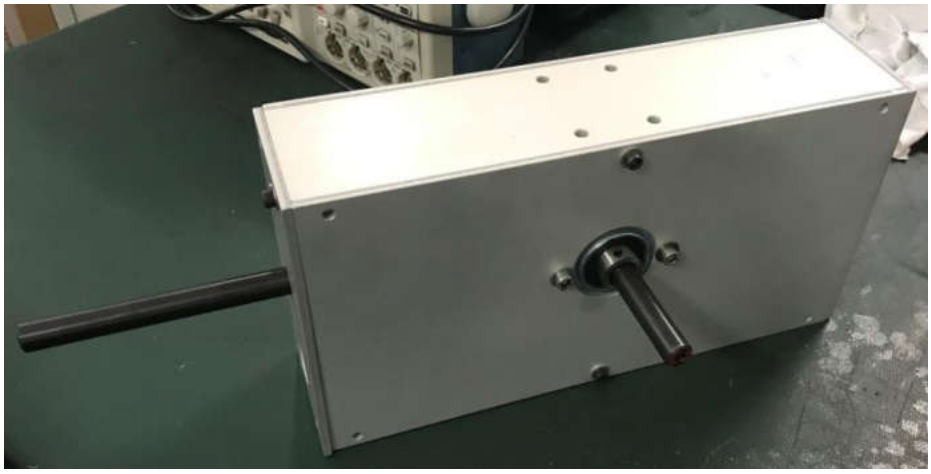

Fig. 2. Prototype of the Motion Transformation Device.

Theoretical models results have been benchmarked against those obtained from a reduced scale prototype (Fig. 2) showing very good agreement.

Tests have also been performed to evaluate the actual mechanical efficiency of the device.

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Acknowledgements

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312 - Technology in engineering education: the sustainable enterprise business game

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Keywords: Sustainable education, Business game, New educative technologies, Reskilling and Training

The aim of the article is to describe the reasons and the creation model for a business game designed to simulate a sustainable business model, a game that will then be applied within engineering education. Our research acknowledges the key relationship between the crucial role played by businesses embracing sustainable business models and the increasing use of digital platforms for education on sustainability goals. By integrating these components into the university curriculum, a comprehensive approach emerges that fosters the development of knowledge, essential skills, attitudes, and values dedicated to creating sustainable businesses of the future, developed by tomorrow's managers. Through the business game, individuals not only gain an understanding of the complexities of sustainability but also actively engage in initiatives aimed at promoting social impact and ensuring a sustainable future for generations to come. This digital business game for sustainability education is primarily dedicated to university students: especially those in engineering, but also those in other faculties, with the aim of providing instructions on how to start entrepreneurial activities through sustainable business models. This study contributes to the understanding of sustainable business practices and innovative educational methodologies, in line with the global imperative of sustainability.

113 - Modifications of a Back-to-back Geared Test Rig for a State-of-the-art Analysis of Its Oil Flows

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1 Extended abstract

Over the decades, the design of geared transmissions has developed in many ways; a development that has been supported by advances from a technological point of view. Whereas, long ago, the main requirement of a gearbox was its mere functionality, transmissions must now be reliable, lightweight, smooth-running, and efficient all at the same time. To guarantee all these functionalities, a state-of-the-art design of a gearbox requires a holistic approach to its design, adopting numerous analysis methodologies to study the gears and the system surrounding them. One of them is Computational Fluid Dynamics (CFD) modelling, which is used both to estimate the losses associated with the splashing of the oil as well as to comprehend the flows within the gearbox itself.

The study of lubrication within gearboxes via CFD is a well-established methodology when the lubrication is a bath one; that is, with gears immersed within an oil bath contained within the case. However, bath lubrication has the disadvantage of being not very efficient and, because of the volume of oil, very heavy.

More advanced applications thus do not use this method to lubricate the system but rather jet lubrication (also known as oil injection) in which the critical components are lubricated by oil released from calibrated holes. Under such lubrication conditions, there is an industrial interest in the study of the oil flows, mainly to insert appropriately the sub-systems used for the punctual analysis of the lubricant properties, their eventual variations as well as the contamination of the oil itself.

However, differently from the case of bath lubrication, the numerical methods used to analyse this lubrication condition are yet the object of scientific research and necessitate an experimental validation of the models themselves as well as of their application to each single specific case. As in the case discussed here, these CFD models need geared test rigs in which it is possible to conduct both global and local measurements that can provide as much information as possible for the validation of models estimating the oil flow behaviour.

Hence, by firstly presenting its state-of-the-art, this work discusses the test methodologies that can be employed to study the lubricant flows within an experimental gearbox. It then discusses the modifications that have been made to a back-to-back test rig in order to integrate such measurement systems into it.

213 -Enhancing Snowboard Design for Ollie Performance through Multibody System Dynamics and Genetic Optimization

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The ollie, a fundamental manoeuver in snowboarding, serves as a basis for various tricks requiring high altitude and extended airtime. The maximum ollie height d pends on the snowboard's geometry and structural characteristics. In a recent study [1], the influence of these properties is investigated. To this end, a flexible multibody (MB) dynamics simulation is built up in the C++ based Python package EXUDYN, where the snowboard is modeled by geometrically non-linear finite elements (FEs) with an absolute nodal coordinate formulation (ANCF), snow contact is considered by a penetration depth and velocity proportional normal force and ollie motion is achieved by globally imposing measured loads to the bindings; see fig. 1. To maximize the height, an optimization procedure is presented, utilizing a genetic optimization algorithm to optimize geometrical and structural snowboard properties interpolated with B´ezier curves.

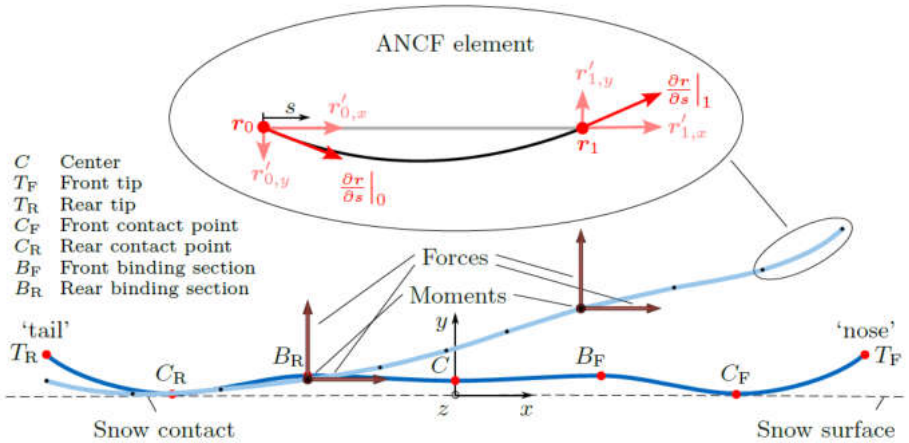

Fig. 1: Scheme of 2D flexible MB dynamics simulation set up in EXUDYN.

The typical ollie motion is achieved by imposing measured forces and moments at the binding section over the period of time of 2 s. The takeoff and jump is visualized in the temporal sequence in fig. 2 from 1.05 s to 1.35 s.

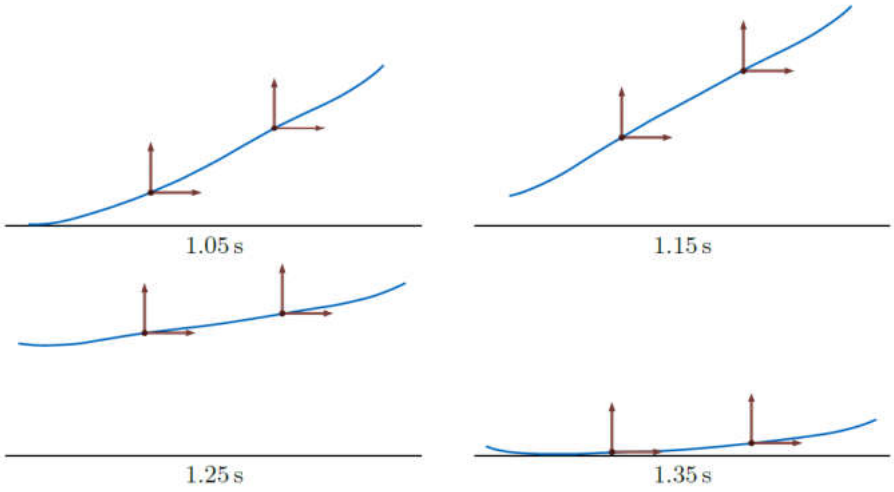

Fig. 2: Temporal sequence visualizing takeoff and jump of a typical ollie motion.

The optimization procedure yields significant improvements, as summarized in tab. 1. Optimizing the camber line and the bending stiffness distribution leads to improvements. Less damping as well as lighter boards lead to higher jumps. Virtually no benefits in optimizing axial stiffness and damping distributions are found. Furthermore, the strain energy stored in the board during takeoff is a useful indicator for estimating ollie heights. Further investigations will take a more advanced and realistic rider interaction into account.

Optimized property	Trend
Axial damping	–
Axial stiffness	–
Width	–
Camber	↗
Bending stiffness	↗
Bending damping	↗
Dimension	↑
Mass	↑

Table 1: Influence of geometrical and structural properties on ollie height.

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313 - The certification of an entrepreneurship competence during an interfaculty business challenge

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Keywords: Entrepreneurship Competence, Certification of Competence; Challenge-based Learning.

This paper presents an ongoing certification process of entrepreneurship competence, where students from diverse faculties (especially engineering and economics) participated in a week-long challenge-based learning experience. The RQs are: *1) To what extent can the students' competence developed during a challenge-based experience be certified? and 2) What are the challenges?* An entrepreneurship competence is one of the key competences for lifelong learning for full employment, citizenship, self-fulfillment, and inclusion. The EntreComp framework [1] found a consensus in Europe on what an entrepreneurship competence is. While the number of entrepreneurship education programs offered around the world is growing, research into the assessment of entrepreneurship education programs is still lacking [2]. Moreover, reflection proves necessary during assessment so that students can raise awareness on their competence development [5]. A process entailing certification of competence can lean on the European Qualification Framework [4], indicating levels of attainment for competence development according to autonomy and responsibility.

This study deploys the case study methodology [6], with a in depth study of a small unit contextualized in time and space. The challenge-based learning event was based on Design Sprint and held at the Free University of Bolzano between 26 February and 1 March 2024. It involved 31 students coming from diverse faculties. They were first placed into small groups and received the challenge from a local company. Coached by experts, students worked on a solution, and at the end of the week, they pitched it to the company. Eventually, 18 students gave their consent to participate in the certification process. The learning outcomes were selected from the EntreComp framework [2] and a previous study [3] on a similar Design Sprint event. These learning outcomes are work with people of different backgrounds; apply new tools and methods; manage time effectively; stay focused and do not give up; present an innovative idea or concept; design a new product or service that has potential end users or clients.

This study gathered data through three sources of information: a) a reflective survey filled out by students before the Design Sprint event; b) observations from coaches through grids during the event; c) a student's survey just after the event. Surveys a) and c) had both a narrative part where students explained the contexts where they developed these learning outcomes, and a Lickert scale where they had to rate the level of mastery.

Concerning the coaches' observations b), for each selected learning outcome, the grids contained written observations and the EQF level attained. The three coaches met the researchers before the Company Sprint to discuss the shape of the grids. They also met the researchers after the event to find a common approach to fill the grids.

Concerning RQ1, students rated a significant improvement (test of Kruskal-Wallis, $p < 0.05$) only for three entrepreneurship related learning outcomes: work with people of different backgrounds; manage time effectively; present an innovative idea or concept. Eventually the certification relied mostly on the coaches' observations, and therefore the meetings with the coaches before and after the event proved key to establish a common and reliable approach.

Considering RQ2, one of the challenges was for the coaches to distinguish between observations and judgment as two different moments of the certification process. It was difficult for two of them to concentrate on observed behavior connected to the specific EQF level, instead they wrote a judgment. Another challenge was to gather data for each participant and for each learning outcome. A challenge for the researchers was to combine all sources of data and to harmonize the coaches' observations. Future certifications could have selected students being observed by two coaches, so that a discussion and agreement on the two observations could bring more data reliability. It is eventually foreseen that, while this procedure gathers competence during its development and is particularly detailed, rich and contextualized, it will not be immediately scalable to large groups or other situations.

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114 - Advances in spline couplings testing

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Keywords: spline couplings, wear, lubrication.

1 Introduction

Splined couplings are mechanical components that find application in many industrial sectors. These components, despite being used and studied for over a century, present issues in terms of damage that have not yet been fully understood and essentially cannot be adequately addressed in the design phase with the current models and methods available in technical literature.

The main issues encountered in the use of such components are primarily related to phenomena of tooth wear and overloads generated by operation under misaligned conditions. The most important fields of application where splined couplings present greater criticalities are in the aeronautical, oil & gas, power generation sectors, and, in recent years, also in the automotive sector, where the development of electric and hybrid vehicles has required their use under new operating conditions, leading to consequent damage issues that are still being investigated.

The only possible approach to investigate the mentioned damage issues is experimental, based on test campaigns with suitable benches capable of reproducing the working conditions that these components face in real-world applications as faithfully as possible. For this purpose, a dedicated test bench has been developed, allowing the

Fig. 1. Spline couplings test rig.

reproduction of operating conditions suitable for various industrial sectors, in particular allowing to test samples working with angular misalignment (Fig. 1).

The test rig can apply torques up to respectively 500Nm, rotation speed up to 2000 rpm, angular misalignment up to 1° and various lubrication modes (oil, grease or dry). The bench is equipped with sensors that allow not only the control of test parameters but also the monitoring of the component, in order to assess its damage state. Another peculiarity of this test rig is the power recirculating design that allow to test components with a mechanical power of about 105kW with an installed electric motor of just 6kW, this allows a great energy saving (Fig. 2).

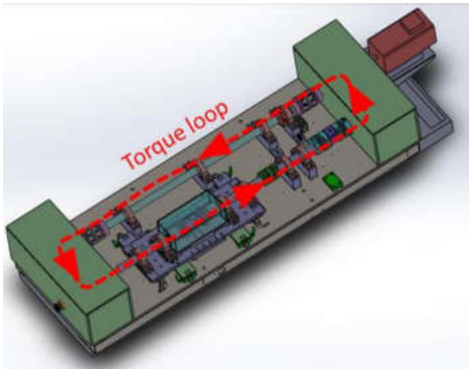

Fig. 2. Power recirculating schematic of spline couplings test rig.

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214 - Redundant Hybrid Robots for resilience in future smart factories

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Keywords: Mobile Manipulator, Redundant Hybrid Robot, Whole-Body Control, Human Robot Interaction, High Level Planning

Due to the shortening of product life cycles, increased product variety and sinking product prices, it is of paramount importance for industries to deploy flexible and adaptive production solutions to increase their resilience. Robotic systems, which are capable of executing a broad range of tasks, play a crucial role in achieving such a resilience, and their application fields will expand even further. Particularly, mobile manipulators, which consist of a combination of mobile robots and stationary manipulators, ensure an even greater flexibility with respect to traditional robots due to their redundancy (both at the kinematic and at the sensoric level), which entails infinite possible ways to plan/execute a motion, of integrating them in the industrial processes and of percieving the surrounding environment. In this paper such a redundancy is analyzed under a unified framework, where the hybrid robot is considered as a serial redundant manipulator, named Redundant Hybrid Robot.

314 - Criticism and proposal of a model for the design and rapid set-up of a training course based on 3D printing

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Keywords: 3D printing learning, Educational Technology, Instructional technologies.

The spread of additive manufacturing and the adoption of 3D printers have generated a sudden adaptation of teaching methodologies in education. The evolution in manufacturing, driven by 3D Printing technology, has required parallel innovation in the criteria and systems needed to transmit mainly scientific and engineering skill.

This research examined the current state of the art in the implementation of Innovative Learning applied to 3D printing. From the analysis of multiple case studies, critical issues were first identified and then grouped according to management, pedagogical and didactic activities and according to the dynamics of 3D printer use.

To address these issues, a matriosca model with a holistic view consisting of three processes is proposed with an integrative approach to the entire training activity in the field of 3D printing, ranging from the conceptualization of the course by the centre or company to final evaluations to ensure continuous improvement in all aspects.

This approach enabled a consistent assignment of critical issues to each phase of the three processes, thus facilitating potential preventive and corrective actions. In fact, once the assignment is completed, notions and potential actions are proposed to be considered to respond to and eradicate each criticality.

115 - Performance Analysis of a Micro Gas Turbine Fed by Ammonia as Fuel with Steam Injection

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Keywords: Micro Gas Turbine, Ammonia, Combustion, Steam injection

This study aims to investigate the possibility of direct burning of ammonia in a micro gas turbine (MGT) from a thermodynamic and turbomachinery point of view. The performance of a 3.2 KWe MGT fueled by ammonia has been assessed using a simulation algorithm, which consists of a series of equations that characterize the various components' pressure losses, the behavior of the heat exchangers, combustor, and turbomachines, as well as the other auxiliary devices. In addition, in this study, the effect of steam injection in the combustion chamber on the MGT performance parameters has been investigated. Higher power and efficiency can be achieved at the rated rotational speed using steam injection. With the STeam Injected Gas Turbine (STIG) cycle taken into consideration, the results indicate that the maximum mass flow rate of steam produced by recovering the heat of the flue gas can be 1.5 g/s, depending on the temperature at the pinch point. Analyzing the MGT's performance, when ammonia was fed and 1.5 g/s of steam was injected, the mass flow rate of fuel dropped, which also reduced the amount of power consumed by the fuel compressor. As a result, there is a significant gain in electric power and efficiency. Adopting the steam injection technique also has the added benefit of increasing system flexibility, as the released heat can be used to make steam, which improves electric performance, or to deliver thermal power, depending on the needs of the users.

215 - Methods for High Performance Phase Change Actuation

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Keywords: Soft Actuators, Phase Change, Soft Robotics.

Abstract. Electrically powered soft robotic actuators will power the next generation of bio-inspired untethered soft robots. Current challenges faced by soft actuators include the requirement of high voltage DC power supplies, insufficient control resolution, limited scalability and challenging integration into the target systems. We present an integrated soft actuation system based on liquid-to-gas phase change, together with a comprehensive design and manufacturing workflow. Physical limits to pressurization rates were experimentally determined, demonstrating significant headroom for further developments, and a new working fluid selection method was also developed. Nonlinear control strategies were shown to be effective at reducing mechanical vibrations and actuation delay times.

1 Introduction

Phase change soft actuators, a technology that leverages the boiling of work fluids to generate internal pressure, are known for their ability to produce high static forces and operate with low voltage power supplies, making them highly versatile [1-2]. However, their useful life is often compromised due to the diffusion of work fluids through the actuator's soft structure [3], and the use of linear controllers has proven to be ineffective in ensuring rapid and robust control. This often leads to extended operation within subcooled boiling regimes, which can cause vibrations and actuation delays, further reducing their useful life. It is therefore crucial to address these issues to enhance the performance and longevity of phase change soft actuators.

2 Results

The implementation of nonlinear controllers that ensure continuous operation within saturated boiling regimes has been found to significantly mitigate vibrations and actuation delays, reducing them by approximately one order of magnitude.

When these systems operate under saturated conditions, they exhibit a pressure control resolution of ±1 kPa, which constitutes less than 1% of the actuation range. This precision in control was verified with water being used as the working fluid. High power operations were also demonstrated, with pressurization rates exceeding 100 kPa/s. This accomplishment sets the stage for the development of future high-power actuators and controllers. The practical application of this technology was demonstrated in the successful integration of phase change actuation into electrically-powered soft robots, as evidenced by a tube-climbing robot and an electrically powered soft gripper, Fig. 1. These advancements underscore the potential of phase change actuation technology in the realm of soft robotics.

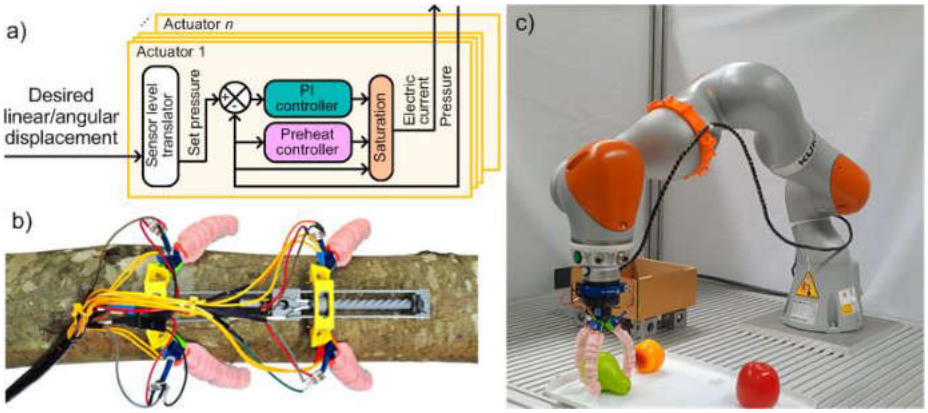

Fig. 7. a) Control diagram for phase change soft actuators. b) Tree crawling robot powered by phase change soft actuators. c) Soft gripper attached to a robot manipulator.

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315 - A Unity3D-based interactive educational game of compressed air system maintenance

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Keywords: Compressed Air System, Industrial Maintenance Training, Game-Based Learning.

This paper presents a novel approach in industrial maintenance training with the development of an interactive game using the Unity3D game engine, aimed at simulating the Compressor Air System maintenance process. Incor-porating Extended Reality technologies, this educational tool strives to im-prove the practical skills and safety awareness of maintenance personnel by simulating real-life scenarios in an engaging environment. This facilitates a deeper understanding of technical challenges and maintenance operations. The study highlights the significance of game-based learning in technical ed-ucation and virtual simulations' role in enhancing the learning experience. Utilizing Unity3D platform's robust graphical and physics engines, the game constructs an immersive 3D industrial environment with interactive modules designed to assist technicians in overcoming common challenges, thereby sharpening critical skills such as decision-making, problem-solving, and ana-lytical thinking. With realistic controls, the game guides participants through the compressor maintenance process, dynamically responding to user inter-actions. This method not only allows learners to refine their technical skills but also to perform maintenance tasks with an emphasis on safety. Perfor-mance evaluation is based on adherence to safety standards and technical accuracy, underscoring the impact of game-based learning and virtual simu-lations in enriching technical education.

116 - Development and Application of a CFD Framework for the Simulation of Fully Coupled Electromagnetic and Heat Transfer Process Inside Electric Motors

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Keywords: CFD, electric motors, thermal management, PMSM, cooling system, electromagnetic losses

In recent years, the thermal management of electric motorsfor automotive applications became a key factor to further improve the motor performance and ensure its efficiency, durability and safety. As a matter of the fact, a motor overheat can result in various issues, including: demagnetization of magnets, degradation of insulation materials, decreased efficiency, shortened lifespan, and even motor failure. In this context, this work aims to improve the comprehension of heat generation phenomena in electric motors and to model the cooling circuit through the integration of CFD, in order to provide guidelines for the optimization of the overall system. To this scope, a novel OpenFOAM solver is introduced, capable of computing electromagnetic quantities and losses, consequently assessing heat generation across various motor components. The combined thermodynamic and electromagnetic analysis of the electric machine, which predicts the heat sources and temperature distribution under the effective electromagnetic operating conditions, allows to optimize the cooling system design and the thermal management strategy. The methodology is applied for the simulation of a simplified permanent magnet synchronous motor (PMSM), to improve the understanding of heat production and guide the development of efficient cooling mechanisms, with the ultimate goal of enhancing both its durability and performance.

216 - Overview of the analysis and testing of a covering system for a telescope

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Keywords: Mechanism design, Digital twin, Automation, Telescope mirror cover, Model validation

The Giant Magellan Telescope will be one of the most powerful telescope on the earth and has been built on the Atacama desert (Chile). It allows to take images of the universe with unmatched quality. Due to the environmental conditions, the seven huge mirrors composing the telescope must be protected by special covers. These covers shall shield the mirrors, when the telescope is not in use, and be automatically removed when necessary. Hence, the covering system needs of a opening mechanism, which allows to fold it in a condition in which covers do not occlude the way of the light. An overview of the analysis performed during the cover design and of the experimental campaign is reported.

316 - The Role of Nordic Entrepreneurship Education for Technical Education

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Keywords: entrepreneurship education, entrepreneurial mindset, TVET, VET

Abstract. Current manifold challenges require the development of entrepreneurial competences by every individual. The aim of this theoretical paper is to ground the features of entrepreneurship education in secondary TVET that best prepare students for engineering courses. Considering entrepreneurship education (EE) as a didactical approach to promote the competence development, Northern Europe takes over the role of a pioneer for EE in school and teacher education. By publishing National Strategies for the integration of EE at school stage and implementing this approach on a cross-curricular basis, concepts for subject-orientated EE have been developed. Technical and vocational education and training (TVET) encompasses a comprehensive range of educational and training approaches at different levels. International studies have shown the relevance of EE for TVET. This article therefore aims to determine relevant features and benefits of Nordic entrepreneurship education as a didactical tool for vocational education and training based on a critical review. This includes the pedagogy of entrepreneurial teaching, especially regarding methods applied and the resulting role of the teacher.

1 Introduction

The challenges of the present are manifold: our society is facing problems such as the coronavirus crisis, climate change and increasing global migration. These challenges require to think innovatively and creatively as well as break new ground to solve them. The aim of this theoretical paper is to ground the features of entrepreneurship education in secondary TVET that best prepare students for engineering courses.

Entrepreneurial competence is a key competence for lifelong learning every European citizen should acquire [9]. The scientific community promotes the integration of entrepreneurship education as a didactical approach to support the development of entrepreneurial competences at compulsory school stage [2, 4, 6, 7, 8]. In preparation for further studies including engineering, Da Silva et al. have given the tight relationship between technology development and entrepreneurship [5]. International studies have already shown the importance of entrepreneurship education for technical and

vocational education and training (TVET) [11]. According to the Eurydice Report and the Nordic Innovation Report, Northern Europe takes on the role of a pioneer as this is the only wider European Region publishing National Strategies for the integration of entrepreneurship on a subject-orientated approach [10], putting high effort to the autonomy and adaptability [4]. Based on a literature review, Schild et al. [18] understand entrepreneurship education in the Nordics as a mostly didactical approach, applied as a cross-curricular theme at all levels of school education and a part of teacher professionalism [1, 13, 14, 15, 16, 19]. Nordic entrepreneurship education is based on social constructivism, a learning theory emphasizing the role of social interaction in the construction of knowledge and understanding. Within the Nordic concept, the development of entrepreneurial competences is supported by applying concepts such as action learning, problem-based learning promoting reflection and teamwork [18].

TVET can be understood as the education and training to develop knowledge and skills for the intermediate professional level [14, 20]. These methods equip individuals with the knowledge and skills essential for occupations across diverse economic and social sectors. The learning occurs through formal, non-formal, and informal channels, encompassing both academic and practical settings. Previous research has shown that entrepreneurship education already has been integrated in Finnish vocational education and training (VET), but special requirements regarding the learning environment, the working culture or the pedagogical approach are needed [3, 16].

2 Methodology

So far, it has been missed out to examine the potential of entrepreneurship education for technical education, especially in a European context. This article therefore aims to determine relevant features of Nordic entrepreneurship education as a didactical tool for vocational education and training based on a critical review. A literature based analysis is appropriate to further investigate the current scientific status of the mentioned subject areas. Following a theory-based comparison and analysis of entrepreneurship education after the Nordic role model and technical education itself, an in-depth look is taken on the potential and challenges of Nordic entrepreneurship education for technical education. Based on this analysis, the potential of Nordic entrepreneurship education for TVET can be examined.

3 Expected Results

It is expected that Nordic entrepreneurship education supports the placement practice of the development of entrepreneurial competences within technical education. The presentation will set out relevant features and benefits of Nordic entrepreneurship education to be implemented in technical education, including the pedagogy of entrepreneurial teaching, methods applied and the role of the teacher. The analysis shows that, among others, the integration of NEE methods promotes the development of entrepreneurial competences within technical education. Therefore, this presentation is a first

step towards further development of entrepreneurship education as an innovative approach for technical education to best prepare students for engineering courses.

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117 - A detailed CFD model for the channel-scale analysis of PEM fuel cells: application and validation considering different distributor layouts

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Keywords: PEM, fuel-cell, CFD, multi-scale, distributor, platinum oxidation

Polymer electrolyte membrane (PEM) fuel cells will play a crucial role in the decarbonization of the transport sector, in particular for heavy duty applications. However, performance and durability of PEMFC stacks is still a concern especially when operated under high power density conditions, as required in order to improve the compactness and to reduce the cost of the system. In this context, the optimization of the geometry of hydrogen and air distributors represents a key factor to improve the distribution of the reactants on the active surface, in order to guarantee a proper water management and avoiding membrane dehydration. To this purpose, the adoption of CFD simulation tools can provide a useful insight into the physical phenomena which determine the efficient operation of the fuel cell (e.g. transport of mass, heat, species, electrons and ions, electrochemical reactions, water formation and removal), providing a valuable support for the design and the optimization of the device at the channel scale. In this work, the open-source simulation library Openfuelcell2, based on the OpenFOAM code, is applied to the detailed simulation of two lab configurations, which are based on different distributor layouts, namely parallel channels and serpentine arrangement for the cathode and anode channels (Figure 1).

The simulation methodology is based on a multi-region and multi-physics approach, where the different components of the fuel cell (namely air and fuel channels, gas diffusion layers, catalyst layers, bipolar plates) are modeled resorting to different computational grids defining different local domains, on which the specific governing equations are solved. Transport phenomena in all of the local domains are coupled and solved simultaneously. In this work, the library has been extended through the implementation of a specific submodule to account for the formation of Platinum oxides at the cathode side, which occurs especially when the fuel cell operates at low current densities. This is a particularly critical condition, since the ORR kinetic is inhibited as result of the Pt oxidation, leading to a reduction of the cell performance up to the 80% of the ideal case in which this phenomenon does not occurs. The model is validated resorting to experimental data acquired on a specific test bench installed at Politecnico

di Milano or available in the literature, showing a good agreement. Then, a detailed analysis of the flow field is conducted in order to provide guidelines for the optimization of the distributors geometry. In particular, the influence of reactants diffusion, water management and electrical conductivity is analyzed considering their impact on the cell performance.

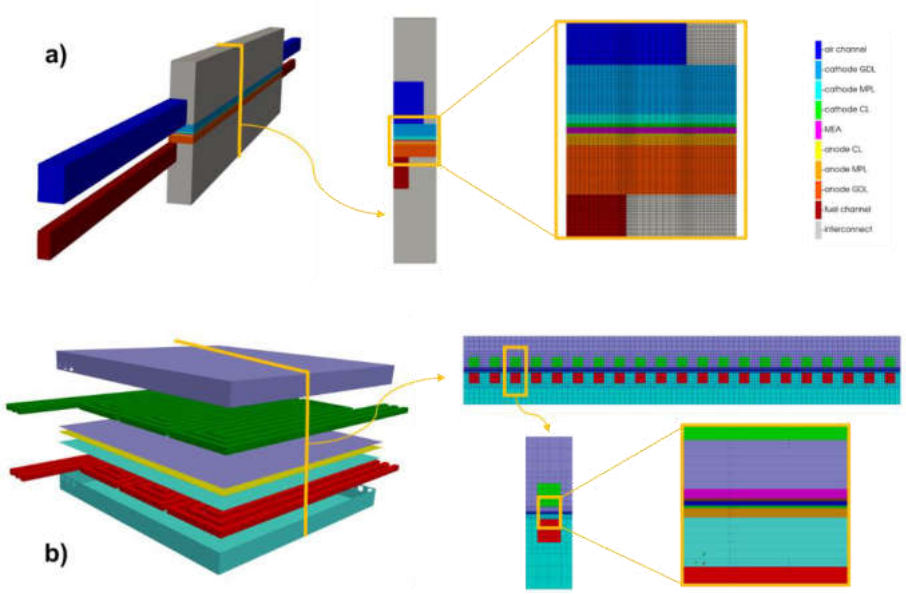

Figure 8. The two different distributor layouts analyzed: a) parallel channels and b) serpentine. An overview of the different scales included in the model is provided.

217 - Shape sensing and damage identification with iFEM on a double bottom structure of a containership

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Keywords: iFEM, SHM, damage identification, double bottom structure, anomaly index

This study presents an approach for conducting structural health mon-itoring utilizing the inverse Finite Element Method (iFEM). The iFEM technique hinges on minimizing a weighted least-squares function, which evaluates the dis-similarity between experimental and numerical strains. This facilitates the recon-struction of a structure's strain distribution using a limited sensor array. Subse-quently, structural health monitoring is performed by finding disparities between the strains reconstructed via iFEM and those measured. In the present work, this framework is applied successfully to a paradigmatic case study for the marine and naval engineering, that is the double bottom structure of a containership, us-ing numerical strain measures. Furthermore, it is shown how the choice of a good sensor network affects dramatically the iFEM displacement reconstruction and needs to be carefully located in practical ship applications, where a lot of con-straints are present. Finally, an anomaly quantity is devised to portray the state condition of the structure by comparing the strain recorded at a designated sensor location with the corresponding strain reconstructed by the iFEM algorithm at the same position, when the structure is damaged due to an extreme event like an explosion in air. The present work proposes a preliminary damage diagnosis framework with iFEM that can be exploit in real marine structures applications in a Digital-Twin framework.

317 - Data Spaces for Leading Future Innovation Processes

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Keywords: Data Space, Data Sovereignty, Innovation

Data and data management have got an eminent meaning in innovation processes, as they often require sensitive information from various external legal entities. Fairly often the data issue turns out to be a major barrier in innovation projects because companies are not ready to share their expertise and want their know-how to remain secure and protected. Data spaces represent a new approach to fostering highly adaptive ecosystems, designed to incorporate essential features that safeguard the interests of all participating data providers during the exchange process, regardless of the field. Therefore, a data space designed for innovation can significantly enhance speed, security, traceability, and – most importantly - the trustworthiness during the most sensitive data exchanges. This paper talks about the concept of data spaces for innovation, how it can be built and demonstrates how a specific funded project helps to implement an innovation-oriented data space works.

118 - A Multiphysics CFD Framework for the Simulation of Automotive Advanced After-Treatment Systems Equipped with Heating Devices

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Keywords: Computational Fluid Dynamics, After-Treatment Systems, Emissions, Heat transfer, Catalytic reactions

In recent years several efforts have been dedicated to cope with the new emission standards severe conditions and to improve the thermal management of the catalyst. In this context, the strict control of pollutant emissions at the cold start represents a crucial point to comply with the regulation limits, since the initial conditions are the most critical one for cumulative emissions. In order to speed-up the light off of the catalytic reactions, the adoption of heating strategies to increase the temperature of the catalytic substrate in the early phase of the engine start is regarded as a promising solution. Possible technologies are based on the adoption of electrical heated catalyst (EHC) or burner-based systems.

The present work provides an accurate description of a simulation framework developed on the basis of the open-source code OpenFOAM to thoroughly investigate such applications. Modelling efforts have been dedicated to deeply characterize the multiphysics phenomena that affect a typical after-treatment system: flow through porous media, heat and mass transfer, catalytic reactions, storage of chemical species, liquid condensation and transport. For the specific case in which electrical heated catalyst (EHC) is present, the model has been extended with: a) the solution of the electrical circuit of the EHC to provide an accurate description of the non-uniform temperature distribution of the coils heated by Joule effect and b) a specific model for the radiative heat transfer from the porous EHC, which plays a significant role in the thermal balance of the device and therefore for the accurate prediction of its maximum temperature. The simulation framework allows to accounts for the thermal evolution of all the components included in the after-treatment system (catalysts, metallic walls of pipes and canning, thermocouples), monitoring eventual critical condition in terms of maximum temperatures. Moreover, the CFD model can be coupled with a specific thermomechanical solver based on finite-volume formulation, in order to provide information about critical conditions in terms of mechanical stress and fatigue.

The simulation model is validated considering an experimental test configuration, suitably instrumented to provide temperature measurements at different locations under different operating conditions. Then, a complete exhaust line has been simulated, analyzing the evolution of the temperature of the catalytic substrate during the different phases of the cold start. The adoption of a burner-like system and of an electrically heated catalyst is simulated and the catalytic activity of a conventional metallic three-way catalyst is monitored. As such, the advanced modelling framework allows to investigate the effects of the peculiar features of each specific catalyst heat-up technology, highlighting the benefits in terms of catalyst light-off time with respect to the baseline configuration and comparing the two different heating strategies.

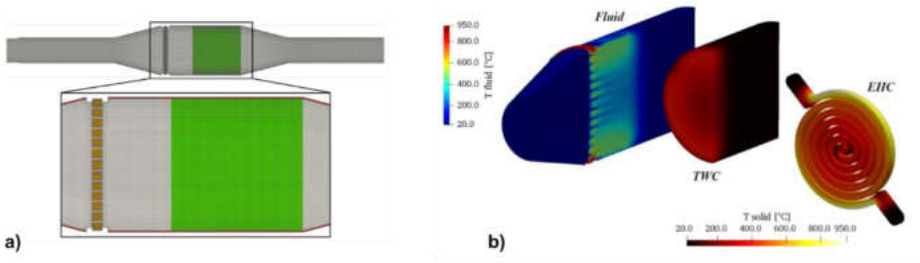

Figure 9. Overview of the simulation framework: a) computational grids for the different domains (fluid, metallic walls, EHC, catalytic substrate) and b) temperature field computed for the different domains.

218 - Validation of a wheelset finite element model for static structural analysis and inverse force identification

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Keywords: Railway, Instrumented Wheelset, Strain Gauges, Finite Element Modelling, Inverse Force Identification.

This paper presents the validation of the strain measurement chain of a static model of an instrumented wheelset for railway applications equipped with strain gauges, involving the inverse measurement of contact forces exchanged at the wheel-rail interface during running conditions. The case study reproduces a test known as the "deformation test", in which the strain of a specific surface is evaluated at various points to reconstruct the punctual trend of deformations. The finite element model is compared with reference experimental results obtained through a static calibration bench for railway axles. Considering the uncertainty in the actual measurement chain, a good agreement is achieved between experimental measurements and synthetic data with average relative errors of 5%. For further validation, the inverse force identification and the selection of radii with greater sensitivity to forces and low relative error with experimental data, is also presented based on strain gauge influence coefficients, obtained solving the inverse system of strain equations with linear superposition technique and Moore-Penrose pseudo inverse of the load matrix.

318 - Blended Intensive Programmes as effective and innovative solutions to train the engineers of the future

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Keywords: engineering education, Industry 4.0, Blended Intensive Programme.

1 Introduction and research purpose

During the last few years, the Fourth Industrial Revolution also called 'Industry 4.0' has introduced a new era of digitally networked production [1]. The main objective of Industry 4.0 to increase connectivity on the shop floor has however been progressively accompanied by an increasing attention to human-centricity, sustainability, and resiliency, thus leading to a new industrial paradigm: Industry 5.0 [2].

Besides impacting the manufacturing and business processes, Industry 4.0 and 5.0 are disrupting labor markets, leading to the emergence of new skills and capabilities for the jobs of the future, including analytical and creative thinking, together with self-efficacy skills of resilience, flexibility, and agility [3]. In this context, educational institutions are called upon to provide the necessary skills and innovation processes, thus transforming the engineering education [4]. At the university level, degree courses are currently being adapted to Industry 4.0 and 5.0 requirements, but, at the moment, training opportunities in the field of digital and sustainable manufacturing are still limited. This calls into question the need to reorient education towards sustainable manufacturing in a way that contents, methods and expected learning outcomes are appropriately harmonized. The present research aims thus to answer the following research questions:

RQ1: What is the best way to structure an educational programme addressing challenges and opportunities of the digitalisation of manufacturing companies?

RQ2: What is the added value of such a programme for the students?

2 Methodology

To answer the research questions, we adopt a single case study methodology. Qualitative case studies, besides being the appropriate solution to answer how, what and why questions are a suitable research methodology for entrepreneurship education [5]. The educational initiative selected as a case study is the Blended Intensive Programme (BIP) in "Digital Transformation in Manufacturing and Engineering Design" organized in the academic year 2022-2023 by the Free University of Bozen-Bolzano (Italy), in collaboration with five European partner Universities belonging to the Euclides network: University of Antwerp (Belgium), KU Leuven (Belgium), University of Girona (Spain),

University of the Basque Country (Spain) and University of Udine (Italy). Blended Intensive Programmes (BIPs) are short, intensive programmes financed by the European Union Erasmus+ that offer students and/or staff the opportunity to undertake a short-term physical mobility abroad.

The BIP in "Digital Transformation in Manufacturing and Engineering Design" aimed to provide students with an introduction to the main Industry 4.0 technologies both from a technical and managerial point of view. Beyond that, students also got the possibility to meet and cooperate with other students and professors from different countries and universities in an international and multicultural environment. Altogether, the initiative involved 31 students and 19 professors/researchers from 3 countries (Italy, Spain, Belgium) and 7 universities.

3 Results and contributions

The initiative took place in March and April 2023, with virtual activities and one week of in-presence lectures in Bolzano (Intensive week). The teaching format of the Intensive Week combined theoretical lectures, exercises, labs, and project works, delivered by professors coming from different universities. The students were also divided into groups and had to work on a specific project linked to the course topics.

In addition to the high level of teaching, one of the main strengths of the selected BIP was the opportunity to undertake an internationalization experience that combines short physical mobility with virtual mobility, integrating several learning approaches and formats. The students, who evaluated the course through a survey, also reported a positive experience in terms of international connections, in-depth knowledge of the current 4.0 trends and vision of the industrial applicability.

Overall, the presented BIP represents a good and well-structured solution to reshape and update engineering curricula and pedagogy for manufacturing according to the concepts of Industry 4.0 and 5.0, while providing students with the necessary competences to address major digital challenges that Europe is currently facing.

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119 - CFD insights into gear jet lubrication: exploring objectives, challenges, and methodologies through a literature review

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Keywords: CFD, Tribology, Oil Jet, Efficiency, Mesh Handling

Gear jet lubrication, although highly efficient, presents significant challenges for reliable study and design due to its complexity. Over the last decades, Computational Fluid Dynamics (CFD) has emerged as a valuable tool, providing both qualitative and quantitative analyses to enhance the design of gear lubrication systems. CFD applications encompass predicting impingement, simulating oil spread-ing behaviors, quantifying lubricant flows in the engaging area, estimating heat dissipation, and evaluating load-independent power losses resulting from churn-ing, squeezing, or windage. Scientific investigations include diverse complexities of gearing systems, ranging from single spur gears to sophisticated configurations such as planetary and spiral bevel gearboxes. Various mesh handling methods, such as Local Remeshing Approach, Overset Grid, Rotating Reference Frame, Sliding Mesh, and meshless techniques like Smoothed Particle Hydrodynamics (SPH), have been adeptly employed. Both compressible and incompressible models can be found in the literature, as well as isothermal or Conjugate Heat Transfer (CHT) models. The multiple studies consider different turbulence models, such as k-ω or k-ε. Noteworthy studies have undergone experimental validation, reinforcing the reliability of CFD outcomes. The objective of this paper is to collect and categorize the multitude of CFD studies on gear jet lubrication present in the literature, shedding light on commonalities and variations in approaches across diverse scientific works. This paper offers a critical state-of-the-art overview in the field.

219 - Improving the Accuracy of the Floating Frame of Reference Formulation for Rotordynamics Applications

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Keywords: floating frame of reference formulation, stress stiffening, spin softening, rotordynamics

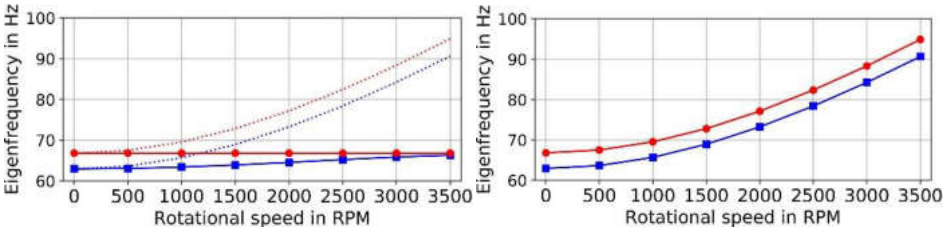
Abstract. Spin softening and stress stiffening are well-known phenomena in rotating flexible bodies. Although the floating frame of reference formulation partially captures spin softening, it does not capture stress stiffening by design. Still, the floating frame of reference formulation is often used for the dynamic analysis of rotating machinery. The stress stiffening effect has its source in nonlinear strain-displacement relationships and not modeling it can yield incorrect simulation results. Current approaches to incorporate stress stiffening are either complex or capture stress stiffening often only for a small range of rotational speeds. This study introduces a simple approach to include stress stiffening in the nodal-based floating frame of reference formulation for rotordynamics applications, enabling efficient transient multibody simulations. The proposed approach is tested by analyzing a bladed and two-disk rotor and achieves an accuracy close to those of finite element analysis.

Spin softening and stress stiffening[3] are well-known phenomena that occur in rotating flexible bodies. While the floating frame of reference formulation partially accounts for spin softening, it does not inherently consider stress stiffening, cf. Ref. [1]. Still, the floating frame of reference formulation is often employed in the dynamic analysis of rotating machinery, e.g., Ref. [2]. Stress stiffening has its origin in nonlinear strain-displacement relationships, and not modeling it can significantly affect a multibody model's accuracy [3]. State-of-the-art approaches typically substitute the linear finite element stiffness matrix with a tangent stiffness matrix that includes the stiffness contribution, e.g., Ref. [1]. Although such approaches agree well with finite element results, they are either complex or often capture stress stiffening correctly only for a small rotational speed range.

In this work, we propose an efficient and easy approach for capturing the stress stiffening effect in the nodal-based floating frame of reference formulation [4] for rotordynamics applications. In the proposed approach, a single stiffness matrix, which depends quadratically on the rotational speed is added to the linear finite element stiffness matrix. Although limited to rotations around a single axis of rotation, the proposed

approach allows capturing the stress-stiffening effect within a user-defined rotational speed range, which needs, in general, not to be small. To assess the accuracy of the proposed approach, we investigate the dynamic behavior of a bladed rotor and a two-disk rotor with the finite element method and the proposed approach and compare the results.

In Fig. 1 the rotational speed dependence of the resonance frequencies of the two-bladed rotor determined with the conventional floating frame of reference formulation (FFRF) (Fig. 1a, thick lines), the proposed FFRF (Fig. 1b, thick lines), and Ansys (dotted lines) is shown in the frequency range of 0 - 100 Hz. As can be seen in Fig. 1a, the conventional FFRF – in contrast to the proposed approach (see Fig. 1b, mean deviation approx. 0.02%) – gives incorrect resonance frequencies when the rotor is subjected to rotational speed.



(a) Conventional FFRF (b) Proposed approach

Fig. 1: Campbell diagrams for the considered two-bladed rotor

In conclusion, this study demonstrates the importance of accounting for the stress stiffening effect in the floating frame of reference formulation for rotordynamics applications and presents a simple approach for incorporating it. By incorporating a proper stiffening term and appropriate modes, the proposed approach can accurately represent the dynamic behavior of rotating structures, which is crucial for rotordynamics applications in various fields of engineering.

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319 – Sustainable aspects of intermodal transport: A systematic literature review on the current state

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Keywords: Combined transport, carbon emission, intermodal transport, road-rail

The growing importance of the environment has attracted the attention of industry, the public, associations, and governments, with the transport sector standing out as a significant source of pollution. Recognizing the unsustainable growth of road transport, the European Commission (EC) called for a shift to alternative modes of transport in 1995. In line with the EU's goal of climate neutrality by 2050, a 55% reduction in greenhouse gas emissions is targeted by 2030. This study examines intermodal road-rail transport as a potential solution to the industry's environmental problems. A systematic literature review examined 121 papers from the SCOPUS database, of which 30 were selected for full-text analysis. The analysis reveals the current state of research, including benefits, barriers, case studies and proposed solutions. Infrastructure emerges as a critical factor and, despite different scenarios, there is consensus on the potential benefits of intermodal transport in reducing emissions and costs. The paper argues for further research to develop tools and software to facilitate the adoption of intermodal transport and encourage a transformative shift in the current modal split.

120 - Simulation of the churning losses of ordinary gears: Lagrangian Smooth Particle Hydrodynamics approach

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Keywords: Gears, Lubrication, SPH, Churning

With the increasing power density of the geared transmissions and the demand of more and more reliable systems, lubrication is becoming a main concern. Optimizing the lubricant supply implies not only a reduction of the power losses and increase of the system efficiency, but also a decrease of the operating temperatures and higher reliability. This paper aims at presenting a meshless Lagrangian approach for the simulation of the churning of a spur gear pair. The numerical results have been validated via experimental measurements on a back-to-back test rig under different operating conditions. The models have been implemented in the open-source environment DualSPHysics. The results have been compared to experimental data as well as numerical results obtained with mesh-based approaches with the aim of assessing the accuracy of the new method.

220 - An objective FE-formulation for Cosserat rods based on the spherical Bézier interpolation.

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Keywords: Non-linear space rods, Objective interpolation, spherical interpolation, Bézier elements, Cosserat rods.

Following [1], a generalization of the spherical linear interpolation (or slerp) for the finite rotations to the case of more than two control variables on SO(3) is given in order to design an objective FE-formulation suitable for the non-linear analysis of curved Cosserat rod.

The initial curved geometry is constructed by the De Casteljau's algorithm for which the control values satisfy specific boundary conditions analogously to high-order Hermite interpolation, see for instance [2].

In this way, the same Bézier interpolation of high-order degree can be used to represent the placement of the centroid curve and the orientation of the crosssection in space.

Iterative algorithms like De Casteljau's algorithm are defined for the spin and the Darboux vectors, indicated as T-slerp and D-slerp, respectively. The obtained tangent basis functions represent a generalization of the polynomial Bèzier interpolation and reduce to those introduced by Crisfield and Jelenić for a two-point interpolation [3].

The rod formulation obtained is invariant under a rigid rotation (objective), so the patch-test concerning the rigid body motion is satisfied. Furthermore, an optimal path-independence is achieved as verified by several numerical investigations in [4].

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320 - The Influence of Digital Transition and Industry 5.0 on the Success of implementing LARGS Paradigms: Exploring European SME Challenges

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Keywords: SME, Industry5.0, Digitalisation, Lean, Sustainability, Resilience

Abstract. The extended abstract connects the theoretical findings from an SLR on current LARGS frameworks with empirical results based on a set of workshops with SMEs. It investigates the influence of increased digitalisation and a transition to industry5.0. may have on businesses. The findings show several barriers for SMEs to overcome in this transition.

1 Introduction and Problem Description

Supply Chains are exposed to different types of operational and disruption risks. The impact is evident as the EU, its citizens, and businesses face successive shortages emerging from various causes. It is necessary to reevaluate the supply chains to maintain competitiveness through high-performance strategies that mitigate the impacts of potential disruptions and facilitate swift recovery. A crucial factor in reducing the vulnerability is the preparedness and reactivity to unexpected events based on (i) deeper awareness of the risks to which they are exposed, (ii) fast decision-making, and (iii) new strategies and models that consider economic, social, and environmental sustainability. Early works on integrating different sustainability aspects [1,2] have induced a better understanding of achieving resilience, but the EU economy is not resilient in practice. This paper is based on empirical data from industry-academy workshops with SMEs [3] and SLR on barriers in the transition towards Industry 5.0.

2 Research Approach and Findings

We have used a mixed approach: a systematic literature review on current frameworks covering leanness, agility, resilience, greenness, and sustainability (LARGS) and industrial implementation based on [4]. Secondly, an empirical analysis with SMEs on

implementation barriers of LARGS strategies and its relation to digital transition using a multi-case study methodology was done [5].
The literature proves that each of the LARGS paradigms can benefit supply chains, twining them into one single integrated strategy is challenging. Research has highlighted instances where certain principles conflict [1, 2]. Thus, trade-offs between the different principles must be made without fully compromising any of the paradigms. Furthermore, our SLR results show a gap in the literature also investigates how concepts like Industry 5.0 and digitalisation in SMEs contribute to leaner, greener, and more resilient supply chains [6]. SMEs are the backbone of the European economy so empirical studies including SMEs are needed, which is the focus of the empirical part.

In one case study, the transition followed an individual change, while for the three others a set of participatory workshops were implemented where the SMEs could learn from the military and humanitarian logistics in terms of preparedness and agility with a focus on reducing the time to react under uncertainties. The comparison of the two studies indicates that key factors for successful implementation of transition strategies are besides the willingness to share and the trust, above all a transition model comprising of a step-by-step guideline, pitfalls and lessons learned. The results will be presented during the conference.

Acknowledgement

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121 - Simulation of the lubrication of high-speed jet-lubricated gears: study of the impact of the oil droplet suspension on the power losses

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Keywords: Gears, Windage, Churning, Power Losses, Jet-Lubrication

With the rising power density and the need for increasingly reliable mechanical geared transmissions, lubrication has become as a primary design focus. An efficient optimization of lubricant supply involves not just minimizing power losses and enhancing system efficiency but also lowering operating temperatures and improving overall reliability. This paper aims at presenting two Finite Volume Eulerian compressible multi-phase approaches developed in the open-source environment OpenFOAM® for the simulation of the windage power losses of a jet-lubricated spur gear pair operating at high speed. The numerical results have been compared with experimental measurements performed by the Ohio State University on a back-to-back test rig under different operating conditions. The analysis has underlined the fundamental role of the droplet concentrations (oil suspension) in the generation of windage power losses.

221 - Use of lumped mass formulation in the design sensitivity analysis of flexible multibody dynamics

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Keywords: flexible multibody dynamics, floating frame of reference formulation, design sensitivity analysis, consistent mass matrix, lumped mass matrix

The lumped mass approach is shown in this paper to enable a decoupling of the dynamic simulation and sensitivity analysis of flexible multibody systems from the finite-element model. The lumped and consistent mass approaches are compared within a modeling framework utilizing the floating frame of reference formulation. The invariants required for nonlinear system parameters are obtained by summation operations with the lumped mass approach, allowing for a decoupling from the finite-element formulation. This is in contrast to the consistent mass approach, where inertia shape integrals are evaluated based on the element shape functions. The derivatives of the system parameters and the sensitivities of the invariants enable the same decoupling for the sensitivity analysis. Further consequences of using a lumped mass approach regarding number of elements, dynamic and sensitivity responses and computation time is compared with a consistent mass approach.

321 - Enablers, barriers, and opportunities for the implementation of circular economy practices in small and medium-sized enterprises: An explorative systematic literature review

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Keywords: sme*, circular econom*, implementation

The importance of Circular Economy (CE) is increasing for the industry, and particularly for small and medium-sized enterprises (SMEs) who must compete with larger companies to ad-here to the ambitious sustainability regulations set by the EU. Therefore, this paper analyses the current literature on the implementation of CE in SMEs, with a particular focus on the findings of applied research. The authors systematically analyze 26 peer-reviewed articles from several journals on 1) enablers for CE implementation in SMEs 2) barriers to CE implementation in SMEs, -and 3) opportunities for CE implementation in SMEs. Additionally, the authors use a secondary data-based content analysis to identify promising fields of action for future research initiatives. The purpose of this paper is to utilize the developed framework to provide insight into the enablers, barriers, and opportunities that assist SMEs in implementing CE. This allows them to identify helpful factors for implementation at the planning stage, anticipate potential obstacles, and effectively eliminate them from the outset. Additionally, it highlights the opportunities that can arise for SMEs through CE implementation.

122 - SiToLub - Simulation Tools for the Design of Safe and Sustainable Lubricants

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Keywords: Lubricants, additives, simulation, safe, sustainable.

Abstract. The ever-changing scenario that the lubricant companies are facing, due to the continuous update of regulatory restrictions for the chemicals and the more demanding technical requirement of the industry, has led to the use of computational models for the prediction of the behavior of the formulations used. So far, each model has been acting as an isolated item for the prediction of very specific properties, and even the attempts to adopt a multiscale approach fail to capture the complexity of the subject. The SiToLub project, funded under the HORIZON-CL4-2023-RESILIENCE-01 topic, aims at creating an integrated multi-functional digital simulation environment, supported by artificial intelligence, to help the lubricant manufacturers to face the challenges posed by the modern industry. SiToLub will integrate tools to predict human and environmental toxicity, already at the design phase, to simulate the interaction with the environment and with the tribological system, to estimate life-time product performance and friction reduction during use, and to foresee the sustainability performance of the new formulation.

1 Context of the project.

The potential for reducing worldwide CO2 emissions through improved friction and wear in tribological applications is estimated to be approximately 1460 MtCO2 per year, with a related cost saving potential of around 1.4% of global GDP [1]. The need to promote a low carbon economy requires a broad set of measures and initiatives directed towards an extremely broad variety of industrial sectors. Among them, there are also low carbon industries, like e-mobility and renewable energies where lubricants can play a key role in the path towards carbon neutrality. Nevertheless, although friction and wear reduction can have an extremely positive environmental impact, the lubricant itself is composed of a complex mixture of chemicals that are not necessarily

environmentally friendly. Conversely, one of the risks of introducing non-toxic substances in the formulation is the lack of performance. In the last decades, the international authorities have focused their attention on reducing the ecological footprint of lubricants and have continuously created more restrictive legislations and ecolabels to introduce biobased base oils and reduce or eliminate the use of certain type of additives [2].

2 Objectives of the project

The methodology is inspired by three major aspects: (1) the development of predicting tools that can analyse the specific aspects of the lubricants, e.g. toxicity (human, environment), physicochemical properties, tribological performance, life cycle assessment, etc. (2) the interlinking of the tools by means of artificial intelligence (AI) features to predict the SSbD lubricants' performance to facilitate their formulation, (3) the inclusion of each tool in the existing i-TRIBOMAT platform and database, resulting in an integrated solution already at the design phase. Below the generic workflow built on the needs of industrial use cases (Figure 1) and work package distribution (Figure 2):

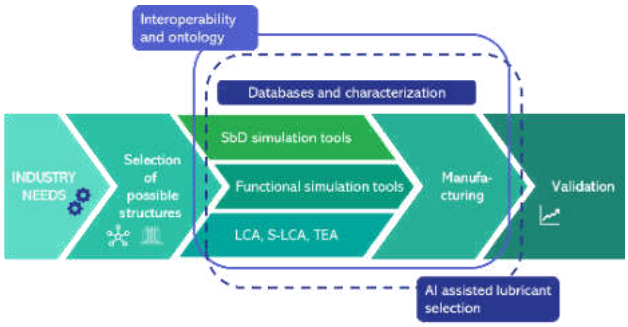

Fig. 10. Workflow for the formulation and validation of a lubricant

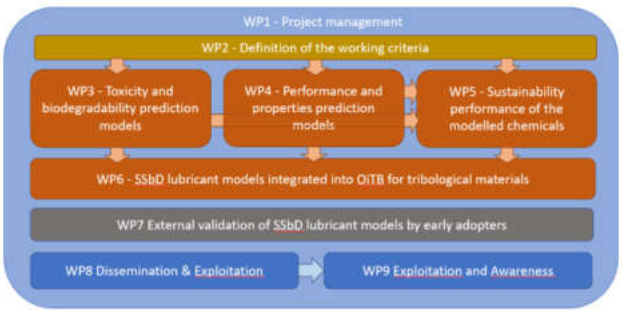

Fig. 11. Work package distribution and interactions with one another

3 Acknowledgements

The SiToLub project has been funded under the Horizon Europe call: HORIZON-CL4-2023-RESILIENCE-01, Grant n. 101138807, duration 2024 – 2028.

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222 - Surrogate mechanical model for programmable structures

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Keywords: compliant mechanisms, programmable structures

Abstract. This work focuses on programmable mechanical structures using autonomous cells capable of reproducing finite element meshes and self-reconfiguration through six-bar linkages. The six-bar linkages, essential for maintaining triangular mesh geometry, are realized as 3Dprintable compliant mechanisms with cross-spring pivots. However, challenges arise from compliance in the hinges and deviation from the desired center of rotation which results in position errors. To address these issues, a surrogate model which is derived from beam elements, is used to predict positioning errors during self-reconfiguration. Finally positioning errors are corrected by solving the inverse kinematics of a hyper-redundant manipulator. This research contributes to advancing programmable structures and predicting and correcting errors in self-reconfiguration processes.

In recent years, programmable matter has garnered significant attention in research owing to its capacity for self-reconfiguration and morphing, rendering it a highly promising material across diverse applications [1]. A crucial property for self-reconfiguration of programmable mechanical structures is, that the cells can preserve the underlying geometry of a mesh [2]. This requirement has led to mechanisms such as six-bar linkages with rotational joints, see Fig. 1a), which are essential for maintaining triangular mesh geometry [3]. In recent research [3], notch hinges have emerged as a promising alternative to rotational joints in programmable mechanical structures. However, challenges persist, notably concerning rotational shifts of rotation, and low stiffness. Addressing this issue, cross-spring pivots [4] have been proposed to increase the stiffness of the cells as another viable option, yet they too encounter rotational offset shifts [3].

The goal of the paper is to derive a surrogate mechanical model for programmable mechanical structures, which considers compliance and rotational axis shift of the compliant joints. Based on the surrogate mechanical model, positioning errors of a hyper-redundant manipulator [5] can be predicted and therein corrected, enabling fast computation and integration into an embedded

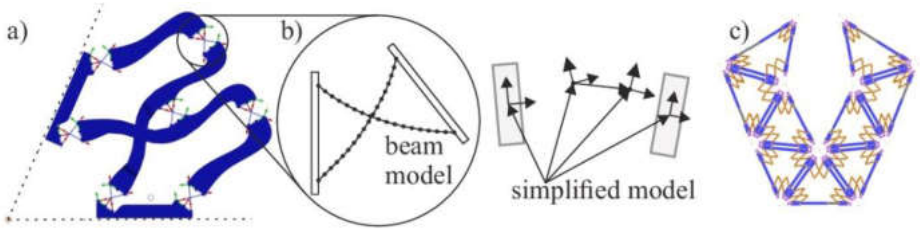

Fig. 1. a) schematic representation of a six-bar linkage; b) cross-spring pivot modeled with beam elements and with a surrogate model; c) hyperredundant manipulator with adaptive triangular cells.

system. In this way, the desired triangular shapes could be prescribed and corrected on an embedded system without measuring the position of the cells.

In the first part of the paper, Absolute Nodal Coordinate Formulation (ANCF) beam finite elements [6] are used to compute the behavior of cross-spring pivots under large deformation, as depicted in Fig. 1b). Subsequently to consider the behavior of cross-spring pivots under large deformation, we identify a nonlinear stiffness matrix for a surrogate model with translational and rotational springs through high-order polynomial fitting, similar to Ref. [7]. In the second part of the paper, we utilize the surrogate model for the multibody model proposed in Ref. [3], enabling the inclusion of friction and an actuator model. Finally, to solve the inverse kinematics of the hyper-redundant system of adaptive triangular cells, see Fig. 1c), different approaches are evaluated. In particular, an approach based on the static solution of the proposed multibody model is explored, facilitating motion in the actuators.

In conclusion, our study illustrates the benefits of utilizing a surrogate model, which reduces computation time compared to beam finite elements by approx. 80% and corrects positioning errors in programmable mechanical structures.

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322 - The application of Collective System Design to develop and improve Small and Medium Enterprises

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Keywords: Collective System Design (CSD), Operational Efficiency, Systems Thinking, SME 5.0, Continuous Improvement, Standard Work

This paper addresses the challenges faced by most Small and Medium Enterprises (SMEs) in improving operational efficiency and competitiveness. Two system design examples are presented. The first is a manufacturing SME that requires adaptable product design and assembly processes within a dynamic, custom job shop environment. The second system design is a service-oriented, higher-education SME requiring the design of standard work and communication of information to achieve student success outcomes. Collective System Design is applied with two different SMEs to determine if the design methodology may be used within both a manufacturing SME and a service SME. This paper emphasizes the potential of Collective System Design (CSD) in addressing enterprise complexity through standard work and continuous improvement. The application of CSD aims to enhance communication, improve customer satisfaction, and reduce waste. The goal is to promote sustainability for SMEs within different types of enterprises. Success is measured through Functional Requirement Measures (FRm), to provide a numerical assessment of how each enterprise Functional Requirement (FR) is achieved.

123 - Digital Twin of a Tribology Test Bench: The Adjoint Gradient Computation for Parameter Identification

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Keywords: tribometer, parameter identification, adjoint method

Abstract. This work discusses the application of an optimization algorithm to determine the parameters for the system dynamics of a tribometer. To determine the parameters, an optimization algorithm is used that compares a simulation signal with a measurement signal from the real test bench. The optimization problem is solved using an indirect method in which the gradient of a cost function is computed with respect to a parameter set. To reduce the computational effort for the gradient determination, the adjoint gradient method is introduced. The method presented in this work avoids the numerical gradient calculation and can be used for the iterative determination of optimal parameters. These parameters form the basis for a digital twin of such a tribometer, e.g. to investigate the coupling between the friction in the model contact and the vibrations caused by the experimental setup.

1 Introduction: Preworks and Research Objective

In a prework, lubricated and also dry tribological experiments have been investigated in [1]. Therein, comprehensive analysis of sensor data from a high-speed acquisition resolves changes within individual measure cycles of the pin-on-disc test. The characteristic frequencies of the system and their temporal evolution are determined via time-frequency analysis, which allows for the detection of localized events and changes during an operation of a pin-on-disc tribometer. Franek et al. [2] have introduced a method for investigating stick-slip phenomena along with additional sensor technology and computer simulation. This approach allows for the determination of both the dynamic and static coefficient of friction during stick-slip experiments, as well as accurate measurement of wear processes at the nanometer scale. The proposed method can be applied to model tribometers for pre-tests of lubricants, materials, or investigations of impacts on model systems. The latter work highlights the importance of accurately characterizing the tribological behavior of material combinations and components in tribological

systems to prevent material and machinery failure. Overall, the mentioned articles demonstrate the importance of developing advanced and reliable methods for investigating wear processes in tribosystems, improving the design and parameterization of mathematical models and simulation tools enabling higher performance ranges in machining applications. However, suitable digital twin models that represent the real behavior of a tribometer will improve the significance of results of models and experiments. Hence, the modeling and simulation of tribometers of selected fields of tribometrology is a promising research field and will show specific solutions for evaluating test conditions and results, as well as for parameter identification.

In this work, the system parameters for a tribology test rig are determined by applying an optimization algorithm. For this purpose, a simulation model is created and the parameters are identified using optimization methods by matching a simulation signal with a measurement signal from the real test rig. In order to solve this optimization problem, an indirect method, see e.g. [3], is applied by computing a so-called adjoint gradient of a cost function with respect to a parameter set. The adjoint gradient method can significantly reduce the computation time while indexing a high number of parameters as e.g. shown in [4]. Moreover, the adjoint method can also be used for parameter identification in frequency domain [5] addressing industrial requirements.

The goal of the present work is a transdisciplinary approach that combines a digital twin of a real tribology test-rig with the adjoint gradient method for current industry-driven research questions. Extending the preworks above [1, 2], in this work, the model is designed for highly efficient optimization strategies arising, e. g., in real time applications. Therefore, the proposed method will be open for optimal control applications for the closed-loop scenario of a tribometer test-rig. With such a setup, it is possible to match the behavior of the experiment with the existing model and to actively control it with regard to desired operating and loading conditions, e. g., to control the contact temperature via dissipated frictional energy.

2 Acknowledgements

Karin Nachbagauer acknowledge support from the Technical University of Munich - Institute for Advanced Study.

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223 - Deep learning enhanced surrogate models for multibody system dynamics

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Keywords: Machine Learning, Neural Networks, Surrogate Models, Multibody System Dynamics

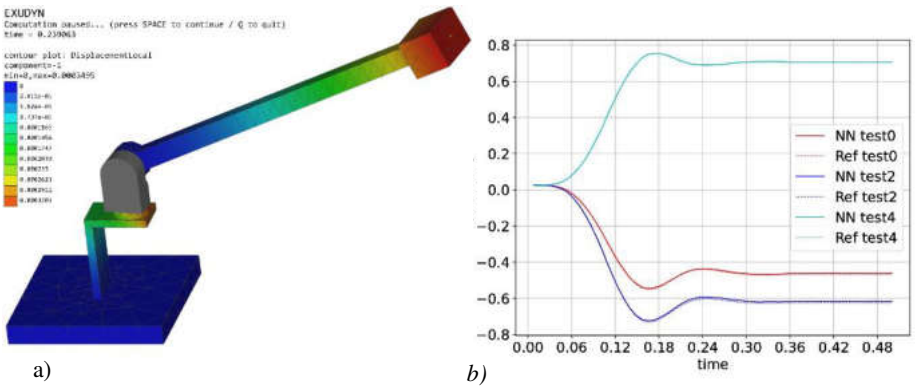
Abstract. Deep learning methods are applied in many scientific disciplines, from image processing to natural language processing, which recently reached broad attention. This study explores deep learning methodologies to replace multibody systems with neural network surrogate models. Different architectures are assessed and applied to systems of varying complexity, starting from single degree of freedom mechanisms to complex flexible multibody systems including flexible bodies. The approaches are evaluated regarding parameters such as training time, network sizes, and depth, with the goal of accelerating the required simulation time.

Standard multilayer feedforward neural networks are capable of approximating any measurable function to any desired degree of accuracy [1], but in practice, many parameters, such as the hyperparameters of the learning process, size of the network or the information available in the learned data, complicate the development of these networks. Deep learning methods can not only be applied to classification and pattern recognition tasks, but also to various topics of computational mechanics, from simulation enhancement approaches, where the deep learning technique interacts with the simulation, to generative methods, such as data generation and design, and simulation substitution [2]. Choi et al. [3] applied simulation substitution to mechanical systems, as pendulums, and more complex systems as the slider crank.

While for many applications specific architectures emerged that achieve remarkable performance on a specific problem, as the transformer architecture in natural language processing or convolutional neural networks for image processing [4], for surrogate models of multibody systems it is not clear how different architectures perform regarding required training time, network size and more.

In this study we apply deep neural networks with different structures and network types, e.g. feedforward networks and convolutional neural networks, and investigate different types of activation functions, e.g. ReLU and tanh, to various mechanical systems. The goal is first to obtain efficient neural network surrogate models, which can be used to accurately and reliably represent multibody models, and second to accelerate simulations. We show several different examples for applications, including friction

and flexible multibody systems. In Fig. 1 an example of a 2R robot with flexible links is shown together with the results from the learned dynamics. The flexible links are modeled using the Floating Frame of Reference Formulation (FFRF). While training the neural network for this model takes 73 seconds, which is significantly longer than the simulation of a single trajectory, taking 0.338s, the forward pass of the neural network is much faster than the classical multibody model and takes on avarage only 0.14 ms.



a) *b)*

Fig. 1. a) Example of a 2R-Robot with flexible links. b) Results from the tested neural network model (NN) compared with the reference (FFRF) model. For all 10 tests, the mean squared error is below $3 \cdot 10^{-5}$.

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323 - Application of Industry 4.0 Technologies for Transparency of Sustainability Data in Multi-Tiered Manufacturing Supply Chains

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Keywords: Supply Chain Transparency, Industry 4.0, Digitalization, Sustainability, Green Manufacturing

Considering the importance of sustainability, current trends in both re-search and policy show that there is a need for significant progress in transparently sharing relevant information with all stakeholders. This paper investigates how Industry 4.0 technologies can enhance transparency in the manufacturing sector's multi-tiered supply chains, with a focus on sustain-ability data. The authors utilize a systematic literature review (SLR), to analyze publications and to identify relevant studies. The paper reveals that modern manufacturing supply chains lack transparency, especially beyond the first-tier suppliers, making sustainability assessment challenging. It emphasizes the increasing demand from stakeholders for transparency in supply chain sustainability. The findings highlight the role of transparency technologies such as IoT and Blockchain in achieving this goal. IoT's ability to capture real-time sustainability data and Blockchain's potential for secure, immutable data sharing are pivotal in enhancing supply chain transparency. Furthermore, the challenges and limitations in adopting these technologies, such as data security and stakeholder reluctance are dis-cussed. Ultimately, the paper proposes a conceptual framework for applying Industry 4.0 technologies in the manufacturing sector. This framework aims to improve transparency and facilitate the integration of transparent practices, aligning with global sustainability goals and regulations. The study's in-sights are valuable for researchers, policymakers, and industry practitioners, offering a starting point for advancing sustainable and transparent supply chains.

124 – Ice Adhesion Research in Trentino-Alto Adige

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Abstract

The presence of ice on airplanes, helicopters, unmanned aerial vehicles (UAV) and wind turbines alters the airfoil, reduces the lift, can lead to stall and increases the drag and weight [1]. On heat pump evaporators, it grows in the form of frost and causes inefficiencies [2]. At the terraXcube facility (Eurac Research), an icing wind tunnel has been developed to address this phenomenon with a focus on aeronautical applications, following the standard CSs of EASA Appendix C [3]. Electrical and/or thermal active de-icing systems require energy to implement as well as increasing weight while the use of anti-freezing compounds [4] implies environmental pollution. With a view to green solutions, there is growing scientific and industrial research into surfaces that passively delay the growth of ice and facilitate its removal. At the University of Trento and at the Bruno Kessler Foundation, surfaces with controlled wetting have been designed, fabricated and tested for multi purposes. The unique skills and infrastructures lay the foundations for a synergistic collaboration with the aim of innovating passive anti-icing solutions and testing them in extreme conditions.

Structured passive anti-frosting surfaces (University of Trento and Fondazione Bruno Kessler)

A cold surface exposed to a humid environment gets covered by frost often following the *condensation frosting* path: first supercooled droplets nucleate, grow and some freeze spontaneously. From these initial ice seeds the frost propagates all over the surface by a percolation mechanism called *ice-bridging*. Ice bridges grow from the frozen droplets to the still liquid ones which freeze once touched. Certain superhydrophobic surfaces are anti-frosting as they enable coalescence-induced condensation droplet jumping (CICDJ) that frustrates the successful ice-bridging for a percentage of droplets and thus delay frosting [6]. We fabricated silicon surfaces with microcones by photolithography and dry etching (Figure 1.a), covered by Aluminium nanoflakes (Figure 1.b) and made hydrophobic by silanization in the FBK facility. The condensation frosting experiments were done in a custom chamber with air at 21 °C and controlled RH=30%. The samples were Peltier-cooled to-11°C. Under condensation frosting conditions, the single droplets grow between the four cones of a unit cell in a stretched shape and move

towards the apex. At a precise volume, they self-eject (Figure 1.c). The driving force is the surface energy release from the stretched shape, as described with analytical models [7]. Due to the self-ejection, the ice bridges fail to reach the liquid droplet with the consequent delay of the frost formation (Figure 1.d). The frost velocity and coverage resulted to be even smaller and inferior to the CICDJ surfaces found in literature (Figure 1.e).

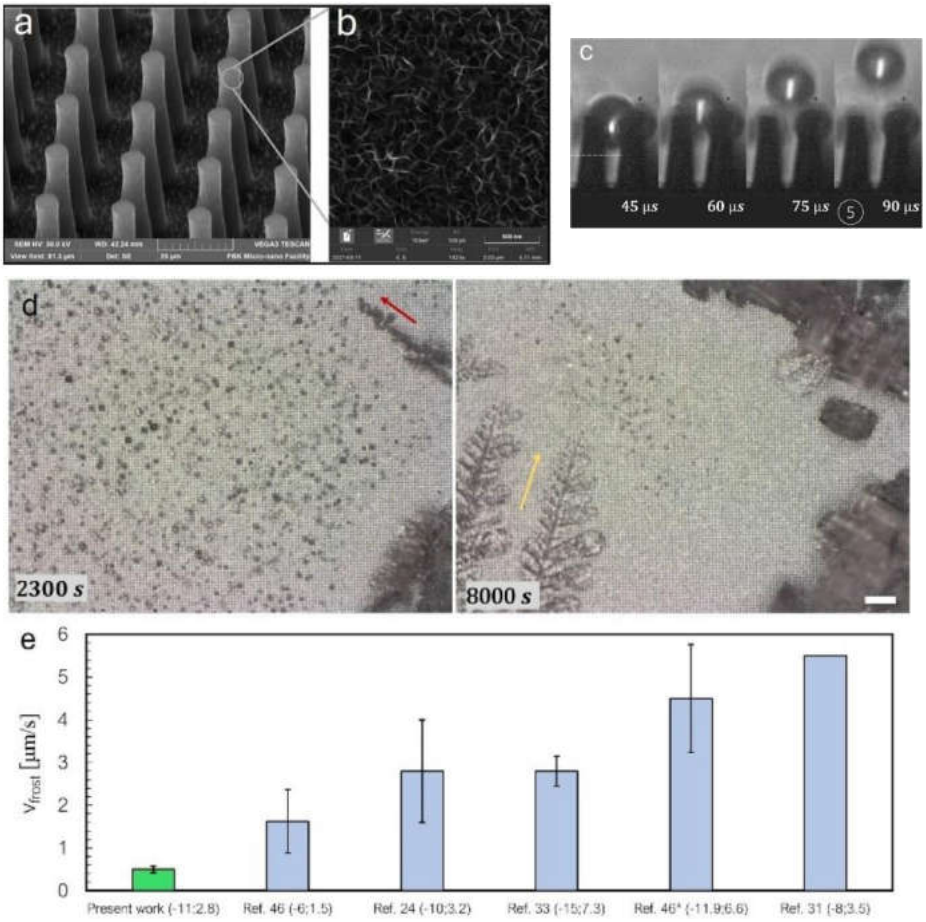

Figure 1. SEM image of a) Si microcones and b) nanostructures obtained by Al deposition and hot water treatment. c) High-speed microscopy of self-ejection. d) Condensation frost process shows few slow dendrites and large areas without frost. e) comparison of frost velocity with the literature [5].

A cold surface exposed to a humid environment gets covered by frost often following the *condensation frosting* path: first supercooled droplets nucleate, grow and some freeze spontaneously. From these initial ice seeds the frost propagates all over the surface by a percolation mechanism called *ice-bridging*. Ice bridges grow from the frozen

droplets to the still liquid ones which freeze once touched. Certain superhydrophobic surfaces are anti-frosting as they enable coalescence-induced condensation droplet jumping (CICDJ) that frustrates the successful ice-bridging for a percentage of droplets and thus delay frosting [6]. We fabricated silicon surfaces with microcones by photolithography and dry etching (Figure 1.a), covered by Aluminium nanoflakes (Figure 1.b) and made hydrophobic by silanization in the FBK facility. The condensation frosting experiments were done in a custom chamber with air at 21 °C and controlled RH=30%. The samples were Peltier-cooled to-11°C. Under condensation frosting conditions, the single droplets grow between the four cones of a unit cell in a stretched shape and move towards the apex. At a precise volume, they self-eject (Figure 1.c). The driving force is the surface energy release from the stretched shape, as described with analytical models [7]. Due to the self-ejection, the ice bridges fail to reach the liquid droplet with the consequent delay of the frost formation (Figure 1.d). The frost velocity and coverage resulted to be even smaller and inferior to the CICDJ surfaces found in literature (Figure 1.e).

Ice on aeronautical applications – terraXcube (Eurac Research)

While the aviation industry has well-established and complex facilities for icing testing [8], the costs are prohibitively high for UAV manufacturers, making the integration of icing testing protocols during the development of small or mini-UAVs particularly challenging. For instance, the estimated cost of a regional transport aircraft icing test is approximately 700,000 €, as noted in the IPHWG Task 2 WG Report - Appendix J [9]. To ensure the safe and reliable deployment of UAVs, realistic environmental conditions must be experimentally tested for the validation and approval of proposed anti-icing solutions. Preliminary testing reveals that ice accretion significantly increases power consumption, with up to a 184% increase due to a reduced aerodynamic lift-to-drag ratio [10]. Therefore, a systematic approach is essential to effectively address the ice challenge, particularly in mountainous areas. The terraXcube icing wind tunnel (Figure 2) was developed in compliance with the EASA document CS-29 [3], Appendix C, with the following icing testing parameters: mean volume diameter MVD 15-50 μm; liquid water content LWC 0 – 3 g m^{-3}; temperature 0°C to -40°C; altitude 0 m to 9000 m and clouds extensions: 4.8 km up to 32.2 km. Initial trials on single-propeller (Figure 3) and quadcopter configurations (with 10” and 15” propeller sizes) under glaze and rime ice conditions at constant MVD or LWC have been performed. This preliminary experimental campaign aims to define and propose a new approach for testing UAVs under icing conditions, adapting EASA CS-29 standards to these smaller yet versatile aerial vehicles.

Conclusions

Thanks to these advancements, the design, fabrication, and characterization of anti-ice surfaces under realistic conditions are now possible for industrial high-tech applications.

Figure 2. Icing wind tunnel

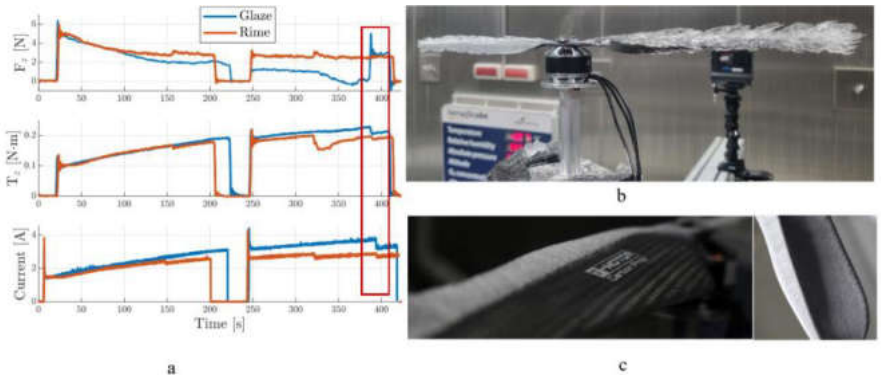

Figure 3. 15"x5" Single propeller icing experiments: (a) forces, torques and current draw corresponding to Glaze (b) and Rime(c) ice formations. The ice shedding phenomenon is highlighted by the red rectangle.

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224 - Vibrations of an inclined cable with lumped mass

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Keywords: cable, eigenvalue problem, nonlinear dynamical system

Abstract. Depending on various system parameters cables display complex vibration behavior. This paper presents an analytical solution for an inclined cable with distributed mass and lumped mass. An accurate analytical description can improve the understanding of these phenomena and be used as benchmark solutions for numerical simulations.

The differential equations governing the in-plane dynamic behavior of an inclined cable with a lumped mass attached to the cable between two immovably fixed supports are given by

$$\frac{\partial}{\partial s}\left[(T+\tau)\left(\frac{d\xi}{ds}+\frac{d\mu}{ds}\right)\right]+\rho(s)g\sin(\vartheta)-\rho(s)\frac{d^2\mu}{dt^2}=0, \tag{1}$$

$$\frac{\partial}{\partial s}\left[(T+\tau)\left(\frac{d\eta}{ds}+\frac{d\nu}{ds}\right)\right]+\rho(s)g\cos(\vartheta)-\rho(s)\frac{d^2\nu}{dt^2}=0. \tag{2}$$

where T is the static cable tension, ϑ is the angle of inclination and g = 9.81 m/s². ξ,η describe the static parametric solution, μ,ν are the displacements from equilibrium (μ longitudinal and ν normal direction), τ is the additional cable tension, and $\rho(s)$ is the cable density per unit length. The variable s is the Lagrangian coordinate that measures the distance along a statically inextensible cable starting from the left support. The cable density ρ including the lumped mass m at position s_m reads as $\rho(s) = \rho_0 + m\delta(s - s_m)$, where ρ_0 is the uniform cable density per unit length and δ the Dirac delta distribution. The lumped mass splits the system into two domains with separate equations and boundary conditions.

Equations (1) and (2) are simplified by neglecting terms of second or higher order and by removing the static equilibrium terms. After a Fourier transform, an eigenvalue problem results. Since the longitudinal vibrations μ are smaller than the transverse vibrations ν, Eq. (1) can be discarded and instead the linearized cable equation

$$\frac{\chi}{EA}\left(\frac{ds}{d\xi}\right)^3 = \frac{d\mu}{d\xi} + \frac{d\eta}{d\xi}\frac{dv}{d\xi} \tag{3}$$

is used as an expression for μ. Here, E is Young's modulus, A is the cross-section of the cable and χ is the change in cable tension in the ξ-direction $\left(\chi = \tau\frac{d\xi}{ds}\right)$. It provides the compatibility between the changes in cable tension and cable geometry when the cable is displaced from equilibrium.

The linearized version of Eq. (2) is solved by a linear combination of Bessel functions, which can be approximated by trigonometric functions. The solution assumes that χ is piecewise constant in the two domains to the left and right of the point load. Combining the cable equations for both domains, as well as using the equation of motion describing the motion of the point load in μ-direction, a system of two equations for the two unknown changes in tension χ_l and χ_r is obtained. The nontrivial solutions require that the determinant of the system matrix vanishes, resulting in the eigenfrequencies. The mode shapes can then be obtained by the linearized version of Eq. (2) and by integration of Eq. (3).

The derived results were validated by comparison with numerical simulations of the linearized Eqs (1) and (2). The presented analytical method finds the frequencies and mode shapes for an inclined cable with a point load. It reproduces the known results by Irvine [1] and Chu [2] for an inclined cable without lumped mass, and extends the results of the paper by Wenin [3] for a horizontal cable with lumped mass. The extension of this theory to any number of point loads is straightforward.

Acknowledgements

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324 - Artificial intelligence in small and medium enterprises: requirements and barriers

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Keywords: Industry 5.0, Artificial Intelligence, Small and Medium Enterprises, Manufacturing, Requirements, Barriers

Small and medium-sized enterprises (SMEs) are the backbone of the economy and in recent years have become the focus of several studies. To promote intelligent and sustainable growth, research and innovation projects are encouraged to create a favorable ecosystem. SMEs are generally adaptable and innovative in terms of their processes and products. Due to the continued competitive pressures that small organizations endure, they are gradually becoming more proactive when it comes to innovation. Digital technologies are changing society and the production sector, and Industry 4.0 (I4.0) marked a new era. The basic idea of I4.0 is automation and comprehensive connectivity, both vertical and horizontal, connecting machines, products and people throughout the entire value chain. Many SMEs began to implement technologies for smart and connected manufacturing and operation systems. The application of digital techniques to companies has had an important effect on the way of living and working. The use of artificial intelligence (AI), virtual reality and robots, among others, is generating different work modalities, and, therefore, education and training. That is why it is intended, from now on, that I4.0 focus on people and sustainability, which is beginning to be known as Industry 5.0 (I5.0). The aim of this work is to be able to answer two important questions: what obstacles to the implementation of AI face SMEs in the manufacturing sector and what requirements they must meet to adopt it. For this purpose, a bibliographic review and five qualitative studies were carried out in Argentina.

125 - Multi-material fittings with carbon fiber reinforcement from AM process: design and characterization

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Keywords: Additive Manufacturing, Design for Additive, Composite, Experimental Mechanics, FEM.

The incorporation of carbon fiber reinforcement into polymer components manufactured via Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) processes presents an opportunity to substitute traditional metal parts, yielding substantial resource savings. To address the outstanding concerns per-taining to mechanical strength, functional adequacy, and reliability, this study en-deavors to redesign mechanical fittings tailored for industrial applications. Specif-ically, it focuses on exploiting polymeric composites processed through additive manufacturing (AM) as replacements for aluminum materials.

225 - A qualitative study exploring maintenance policies of compressed air systems in production

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Keywords: Compressed Air System, Maintenance Policy, Production

Compressed Air Systems (CASs) are crucial for production in various industries and significantly impact global energy consumption. Despite this, maintenance predominantly relies on traditional Corrective and Preventive methods, with literature suggesting that advanced strategies like Condition-Based Maintenance (CBM) and Predictive Maintenance (PdM) are applied less frequently. Although theoretical works suggest that PdM policies could be applied to CAS, practical examples of such applications are scarce. This gap between theory and practice necessitates an investigation into the barriers preventing the adoption of advanced maintenance policies (MP) for CAS. This study adopts a qualitative approach with 20 maintenance managers from various sectors in Istanbul. It aims to reveal the decision-making processes behind MP selection, the integration challenges of CBM and PdM, and the place of CAS in production processes. Findings indicate a cautious approach towards advanced MPs among maintenance managers due to the critical nature of CAS and reliance on manufacturer guidelines. The research reveals that managers recognize the benefits of CBM and PdM, such as increased economic efficiency and extended equipment life. However, there is a notable reluctance to deviate from traditional maintenance methods due to the indispensable role of CAS in production and a preference for manufacturer-recommended practices. Consequently, this study advocates for CAS manufacturers to lead in the development and support of maintenance management systems enhanced by Industry 4.0 technologies. This initiative is vital for tackling CAS maintenance challenges, enabling a shift to more efficient and cost-effective practices, and promoting further academic and practical progress in this essential field.

126 - Characterization of compressive behavior of novel bio-inspired additively manufactured composite sandwich structures

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Keywords: Bio-inspired, sandwich structure, Additive manufacturing, Composites, Mechanical properties

This research study proposes a unique bio-inspired lightweight corrugated sandwich panel manufactured by using additive manufacturing technique, with inspiration drawn from eco-friendly green sandwiches made of Oak-tree cupules as core elements and balsa face sheets. The quasi-static compressive characteristics of the bio-inspired sandwich panels and energy absorption behavior were evaluated by experimental method to examine the effects of geometrical dimensions in terms of load-bearing capability and energy absorption capacity. According to experimental results, the printed panel showed a significantly better performance in comparison to the bio-based sample with the same geometrical dimensions. The peak load and energy absorption of the printed sample was approximately five times greater than those of the bio-based specimen. In addition, the geometrical dimensions affected the performance of the sandwich panels' capacity in terms of load bearing, energy absorption, and specific absorbed energy.

226 - Sustainability assessment: a complex many-objective multi-agent multidisciplinary problem

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Keywords: European Sustainability Report Standards (ESRS), SME 5.0, System of Systems, Many-Objective Multi-Agent Systems, Multidisciplinary Optimization

With the implementation of sustainability laws by the European Union such as the European Sustainability Report Standards (ESRS), companies are forced to assess sustainability targets, impacts, and risks through sustainability reports. Identifying the current situation toward sustainability goals is one of the challenges that companies face. The ESRS standards coupled with the focus on addressing the three pillars of sustainability concurrently serve as compelling evidence that within the System of Systems (SoS) perspective, may be defined as a complex many-objective multi-agent multidisciplinary problem. Complexity arises from the interaction and dependency between different factors and disciplines not only in the higher level of the system design but also within solutions in the lower layers. Furthermore, multiple conflicting human-centric objectives make sustainability assessment a challenging SoS problem. This paper presents a pragmatic analysis of the current situation of organizations and future milestones in the journey to sustainability. The essential steps to achieve a targeted sustainability assessment are presented to address decision-making in the presence of conflicting objectives. A new formulation for sustainability assessment is proposed to have a more practical and feasible solution based on a company's sustainability readiness levels. This formulation shows that even for the same companies with the same functionality the appropriate scenario toward sustainability realization could be different according to their maturity relative to sustainability readiness levels.

127 - Comparison of low-cycle fatigue criteria for the life prediction of AISI 316L

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Keywords: low-cycle fatigue, plastic deformation, strain, failure, fracture

This work is a comparative study of the accuracy of criteria for the life prediction of metals under low-cycle fatigue. AISI 316L specimens were tested in strain-controlled conditions, undergoing low-cycle fatigue. Stress and strain tenors developed during one test cycle were calculated through a finite element model. Subsequently, they were numerically elaborated employing four different criteria for life prediction based on strains and on the critical plane theory, namely the Smith-Watson-Topper, the Fatemi-Socie, and the two Chen-Xu-Huang criteria. For each of them, a life prediction was numerically obtained. By comparing the experimental and the numerical results, it was observed that the accuracy of the tested strain-based criteria varies, depending on the principle at their basis. Some of them represent a reasonably reliable prediction tool, while others tend to overestimate the results, but mainly because pure axial loading is a working condition where they are notoriously not effective.

227 - The influence of electric vehicle technologies on environmental sustainability in industrial reporting: A bibliometric study

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Keywords: Sustainable Mobility, Electric Vehicles, Supply Chains, Logistics, European Sustainability Reporting Standards, Bibliometric Analysis.

This research aimed to investigate the implications of electric vehicle (EV) technologies on the environmental sustainability of industrial reporting, given the critical role that vehicles play in all enterprises. To achieve this objective, this study employed bibliometric and systematic reviews as well as quantitative and qualitative indicators to evaluate the current state of research on EVs. Specifically, the study examined the influence of new energy technologies on supply chains and logistics operations, focusing on the European Sustainability Reporting Standards (ESRS) and the environmental aspect of sustainability. The transportation sector is a significant contributor to greenhouse gas emissions, and the widespread adoption of EVs has the potential to mitigate these emissions. However, research on the impact of EVs on the sustainability of industrial reporting is limited, especially in light of the new ESRS. The central research question is "What is the influence of new electric technologies on environmental sustainability in industrial reporting?" The study argues that the integration of EVs into enterprise operations will lead to reduced greenhouse gas emissions, enhanced environmental sustainability in industrial reporting, and the achievement of the ninth Sustainable Development Goal (SDG), which includes the establishment of resilient infrastructure, promotion of inclusive and sustainable industrialization, and fostering innovation.

128 - Molecular dynamics simulation of fatigue crack propagation in single crystal Aluminum under cyclic loading

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Keywords: Fatigue, Single crystal Aluminum, Molecular Dynamics, Cyclic loading

This research paper focuses on the fatigue failure simulation of aluminum single crystal using Molecular Dynamics (MD) simulations. The investigation was conducted using 3D simulations of Face Centered Cubic (FCC) crystal within the NVE ensemble. Instead of directly removing atom layers, the crack was induced by eliminating interactions between atoms, which resulted in a more realistic simulation. A single edge crack was introduced inside the aluminum lattice and loading and unloading processes were applied to the system as the fatigue strain. Then, the propagation trend of the primary crack inside the lattice was carefully studied. Finally, the crack growth rate versus stress intensity factor was calculated and the results of the MD simulations were validated by a direct comparison of the MD Paris law exponent with available experiments.

228 – Industry 5.0 and SMEs future work competency fields: A literature review

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Keywords: Industry 5.0, SMEs, Literature Review, Competencies, Work 5.0.

The digital revolution in the technology industry is leading towards Industry 5.0, resulting in significant changes in the future of work, particularly for small and medium-sized enterprises (SMEs). To ensure a successful industrial transition, it is crucial for employees to acquire the necessary skills and competencies. In this vein, the present study aimed to investigate the impact of digital and sustainable transformation on the required skills and competencies of employees in SMEs. A literature review was conducted to gather scientific data through a qualitative analysis. The study findings indicate that SMEs are placing increasing importance on transversal, technical, and green competency fields. Furthermore, the study identified forecasting tools that can help predict the future required skills and competencies of SMEs.

129 – Presentation of Associazione Italiana Costruttori Organi di Trasmissione e Ingrannaggi (ASSIOT) Federtec

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Presentation of Associazione Italiana Costruttori Organi di Trasmissione e Ingrannaggi (ASSIOT) Federtec.
In an evolutionary context where product technologies tend to converge more and more, Federtec, the Association representing the Italian industry of Components and Mechatronic Technologies for Fluid Power, Power Transmission, Control and Intelligent Automation of Products and Industrial Processes, confirms itself as the point of reference for the industrial automation sector, focused on the integration of the different technologies used and aimed at representing the entire supply chain. After the establishment of Federtec in 2019 thanks to the merger of ASSIOT and ASSOFLUID (Associazione Italiana dei Costruttori ed Operatori del Settore Oleoidraulico e Pneumatico), since April 2022 FNDI (Federazione Nazionale della Distribuzione Industriale) has also been incorporated into Federtec, adding a new piece to the mechatronic technology supply chain.

229 - Multi-objective modeling of additively manufactured bio-composite based on support vector machine regression

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Keywords: Bio-composites, Fused Filament Fabrication, Support Vector Machine Regression.

Bio-composites, combining eco-friendly materials like wood fibers and bio-degradable polymers, offer exciting potential for sustainable innovation.

However, printing these bio-composites using fused filament fabrication (FFF), presents challenges, and optimizing the printing process is crucial for high-quality, strong, and efficiently produced objects. This study explores the use of Support Vector Machine (SVM) regression for modeling and optimizing the FFF process with Wood/PLA composites as filament. By employing a full factorial plan and constructing 64 test cubes, the study unravels the complex relationships between printing parameters and critical out-comes like relative density and productivity.

To capture non-linear dependencies, a cubic kernel function was used within the SVM model. Cross-validation with a value of 5 ensured generalizability and prevented overfitting to specific data subsets. The results showcase the model's strong predictive power, confirmed by high R-squared values and accurate predictions (low metric values) for both validation and test sets.

Furthermore, the Newton-Raphson method identified the optimal printing parameters that maximize both relative density and productivity (calculated as a portion of volume built in a second). The optimal setting was found with a nozzle temperature of 205°C, a printing speed of approximately 87 mm/s, and a layer height of approximately 1.5 mm.

130 - Experimental and numerical wear characterization by means of Active Thermography technique

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Keywords: wear, Lock-In, Active Thermography

Thermography is a non-contact technique used to obtain thermal maps of a component surface. Active Thermography (AT) has gained a lot of interest in recent years as a tool to characterize thermal properties and fatigue damage in materials, coatings, and components. Hidden flaws can also be detect-ed based on the surface thermal map in a non-destructive way. This paper presents a preliminary experimental procedure where Lock-in AT is exploited to characterize wear damages of a flat steel surface featuring a series of linear wear traces from pin-on-flat wear tests. A dedicated temperature data processing route was set up to correlate thermal signals to the characteristic parameters which may identify the amount of material loss by wear. The results suggest that AT may be a promising, fast, and alternative method to detect and quantify wear on surfaces. An exponential law correlates the wear track width, depth, and area with the intensity peaks of the fundamental harmonics of the pulsed thermal response. Although the sensitivity and reliability of this method is still to be assessed, this preliminary work might pave the way to significant implications for AT in industry in the case of wear on hidden surfaces.

230 - Zero-emission heavy-duty trucks in logistics: a systematic review and analysis of relevant adoption parameters

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Keywords: Heavy-duty trucks, Electric vehicles, Sustainable transport logistics, Decarbonization, Road freight transport

This study examines the challenges and potential solutions associated with the adoption of Zero-Emission Heavy-Duty Transportation (ZE-HDT) in the automobile logistics sector in the EU. A comprehensive systematic literature review (SLR) was conducted using a forward and backward research methodology to identify relevant parameters in the adoption process of Battery Electric (BET) and Hydrogen Fuel-Cell Electric Trucks (FCET). The analysis reveals a complex set of technological, operational, and infrastructural fac-tors that currently affect the widespread implementation of ZE-HDTs. Based on a structured, adapted PESTEL framework, which takes into account operational factors, a descriptive analysis categorizing these factors is presented. In addition, expert interviews were conducted to validate the completeness and to attribute an importance scale to the different parameters. Through this approach, the paper improves the decision-making process in the adoption phase of ZE-HDT by ensuring that no essential aspect is overlooked. This research contributes to the existing body of knowledge by presenting a comprehensive overview, providing clarity and transparency on the state-of-the-art in ZE-HDT adoption to assist researchers and practitioners. This information is then used to derive strategic measures addressed to stakeholders for exploiting the benefits of such vehicles or for conducting further applied research aimed at improving the adoption potential of such technologies throughout the industry.

131 - Active thermography for residual stresses identification in gears

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Keywords: Active Thermography, gears, residual stress

Residual stresses are a topic of great interest in mechanical field since they can impact in a positive or negative manner on both materials and components. During the years, many efforts were done to identify and to characterize residual stresses and, in many cases, for this purpose destructive techniques are required. An innovative Non-Destructive Techniques (NDT) such as Active Thermography (AT), called also stimulated thermography, is widely used in industrial environment to investigate defects inside the material. Recent studies describe the potentiality of Active Thermography also for other mechanical fields like the material characterization or the damage investigation. In this work, an alternative application of Active Thermography is proposed to identify residual stresses generated from surface treatments. In particular, thermal responses were investigated for both samples and gears subjected to case hardening and shoot peening processes. Moreover, a careful analysis on both mechanical and physical properties were performed for both samples and gears aiming to verify the Active Thermography results.

231 - Study on energy efficiency of an electrified railway line

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Keywords: railway, overhead line, electrification, energy optimization

Electrified railways represent one of the most sustainable means of transportation, especially when considering the adoption of Regenerative Substations (RSSs). However, power distribution and collection along these lines involve high investments, heavy maintenance costs and energy losses justified only by high traffic intensities. Also, the construction of overhead lines implies an impact that should not be compatible with constraints imposed by historically or environmentally sensitive sites. In this work, a power line model is proposed and coupled with a previously developed railway model, considering different substation scenarios, conductor sections, and train configurations to evaluate the energy efficiency within a case-study mission profile. The simulation results will help evaluate the effectiveness of extensive line electrification investments.

132 - Directional thermal diffusivity of additive manufactured thin sheets

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Keywords: Active thermography, Additive manufacturing, Image processing, Non-contact measurement, Thermal diffusivity

The thermal responses of two additive manufactured specimens (as built and heat treated) was analyzed for a steel magnetic plate as a case study. The analysis was based on the evidence that variations in the thermal properties of a material can be measured as a phase delay in material thermal diffusion. The specimens underwent active lock in laser thermography testing. The thermal signal post-processing was performed by a in-house Python code which automates the search for the laser beam centroid on the acquired thermal map. The directional diffusivity is then obtained. The results showed that after heat treatment, the slope of the phase diagram changed, indicating a change in thermal diffusivity and hence, thermal conductivity. The results highlight that the thermographic non destructive full field non contact approach can be used to evaluate the microstructure and thermal performance of magnetic steel additive manufactured components.

232 - Planning of smart charging infrastructure for electric vehicles: an Italian case study

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Keywords: EV, Charging Point, Energy Demand, V2G, Smart Charging

Nowadays, the large-scale introduction of electric vehicles requires the definition of appropriate infrastructure devices and software solutions. Consequently, the development of those systems should enable them not only to provide the necessary energy amount, but also to participate to the local grid management, improve energy quality, exploit the potential of non-manageable renewables and support local energy district. The article describes the planning activity of a charging points site located in the area of the central Italy. More specifically, the content includes the analysis of charging procedures and events from the population of users by a local energy provider, identifying vehicle necessities and calculating their expected energy supply based on daytime and local position. The final objective of such clustering is to identify opportunities for energy management, finding and supporting path planning so that it is possible to apply V1G and V2G smart energy management strategies. Also, the analysis explains the suitability of the charging location according to the current user charging behavior and hypothesize the implementation of strategies to both maintain user satisfaction and optimize grid impact on the local energy district.

133 - Induction thermography for surface crack detection during motion tests

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A common challenge in the production and maintenance of critical components is how to quickly localize and quantify surface cracks with the use of non-destructive testing, in many applications that cover the production of thin sheet metal up to the analysis of components such as rails which are very important in the field of railway diagnostics.

Nowadays, different non-destructive techniques with some very specific industrial advantages have been developed to detect surface cracks, e.g., ultrasonic testing, X-ray tomography, eddy current, liquid penetrant, magnetic particle and active thermographic techniques such as induction, conduction and flying laser thermography [1-4].

In particular, induction thermography is a non-destructive and contact-free technique widespread for the detecting and characterizing of surface and subsurface cracks on conductive materials. The presence of a defect or anomaly changes the local distribution of the induced eddy current and, consequently, the temperature field acquired by a thermal sensor.

Suppose there are examples of old and more recent publications that proposed using this technique during static tests, considering different materials and studying the influence of some parameters [1-2]. In that case, there are still few publications investigating the phenomena during motion tests at considerable scan speed [3].

In this work, a commercial inductor up to a power of 4.2 kW is adopted to excite a ferromagnetic specimen with imposed surface-braking cracks of different depths (Fig. 1), considering a coil with a circular shape, up to a speed of about 4 km/h. A cooled sensor is adopted to acquire the thermal sequences, reaching a frame rate of 1500 Hz and a geometrical resolution of 0.25 mm/pixel. During the experiments, a power of about 1000 W is reached.

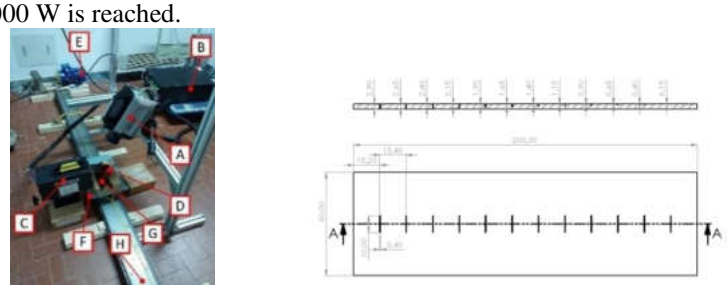

Fig. 1. Set-up adopted for induction tests specimen geometry.

A procedure for data analysis was developed to reconstruct the sequence and obtain a single frame to analyze during the heating or the cooling down; in particular, a single profile is used to collect the data immediately downstream of the coil excitation and obtain an image that corresponds to a precise time of analysis. The obtained results were compared to understand the influence of crack depth and length, as the distance between the coil and the respective crack tips, considering a crack length of 10 mm.

The results (Fig.2) demonstrated a difference of about 0.5 degrees along the crack length, if the two different crack tips were considered for the analysis. If a threshold value based on the and sound standard deviation analysis is chosen to define defect detectability, the crack depth must exceed the value of approximately 1 mm.

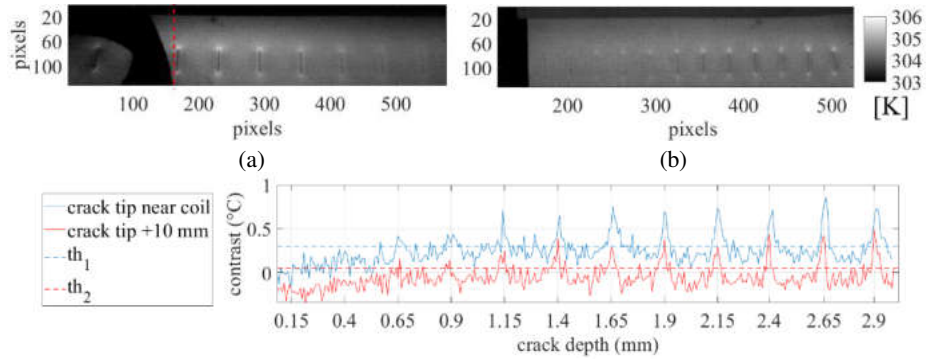

Fig. 2. (a) Acquired thermal during a test in motion; (b) reconstructed sequence immediately after the coil excitation (red dotted line) and thermal contrast along a profile taken in correspondence of the two crack tips.

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233 - Preliminary Design and Simulation of a Return Current Collector for an Innovative Trambus System

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Keywords: Electrical Mobility, Trambus, Current Collection Systems, Path Driving Systems

In this work authors propose an innovative return current collector for Trambus public transportation systems. Trambus is a hybrid transportation systems that conjugate mixed features of trolleybus and tramway systems: Trambus like a trolley bus is road vehicle with rubber tire, but like a tram-way is fed by an unipolar DC catenary. Return current is transmitted through a fixed ground conductor, a rail fixed to ground. This technology is mostly proposed to provide a dynamic fast recharge a road vehicle using a standard DC catenary that can be shared with pre-existing tramway infra-structures. In this work authors propose an innovative current collector that also implement sensing and guidance functionalities to automate or assist the guidance of the vehicle during the dynamic recharge under electrified sections.

P01 - A Novel Concept of Nested Cycloidal Drive

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Abstract. In the present work, an innovative gearbox architecture is presented. The new configuration combines three cycloidal and hypocycloidal gearing stages to achieve the same reduction ratio of a traditional two-stage cycloidal gearbox in a more compact design [1]. This architecture is called "Nested" since it involves stages with internal and external gears arranged one inside the other. A comparison of the solution proposed with the more compact two-stage cycloidal architecture is shown. The gear ratios as a function of the total number of meshing features, i.e. the overall sum of the number of rollers and lobes in the gearbox, are discussed.

1 Introduction

Radical innovations in high power density gearboxes have been reached by developing architectures capable of achieving the same performances of modular trains with dimensions drastically reduced [2-4]. For example, with respect to planetary gearboxes, the Wolfrom topology has been an extremely innovative conceptualization in the early 20th century [5, 6]. By implementing the differential principle of Wolfrom's topology on cycloidal gearboxes, it is possible to design a two-stage cycloidal gearbox that has comparable overall dimensions of a single-stage one [4] (for the same power rating), i.e. Wolfrom-based cycloidal gearbox. This configuration allows reaching Gear Ratios (GRs) comparable with Wolfrom-based planetary gearboxes with a lower number of meshing features, i.e. lobes-rollers for cycloidal drive and tooth-tooth for gears [7]. The solution proposed in this work, which can be implemented with either involute or (hypo)cycloidal gears, allows designing three-stage reduction with comparable axial dimensions to a Wolfrom-based cycloidal speed reducer. This new technical solution has been filed with a patent.

2 Three Stages Nested vs two-stages Wolfrom

In Fig. 4, the difference between the Nested and the Wolfrom solution in terms of |GRtot| for different Total Meshing Features is presented for $\Delta z = 1$, $\Delta z = 2$, and $\Delta z = 7$. Where the Total Meshing Features is the overall sum of all rollers and all lobes in the gearbox. First, it is possible to notice that, considering the same Total Meshing Features, the Nested solutions allow to achieve higher |GRtot| than the Wolfrom solutions. In other words, high |GRtot| can be achieved by Nested solutions with a lower number of Total Meshing Features. Second, Wolfrom solutions have evident design

space discontinuities for |GRtot| values approaching their relative maximum. This discontinuity is less pronounced for Nested solutions which are able to cover a larger design space and thus provide greater flexibility to the designer. Third, taking into consideration solutions with $\Delta z = 7$, the Nested architecture paves the way not only to cycloidal solutions with |GRtot| above 5000 but also to involute gearing.

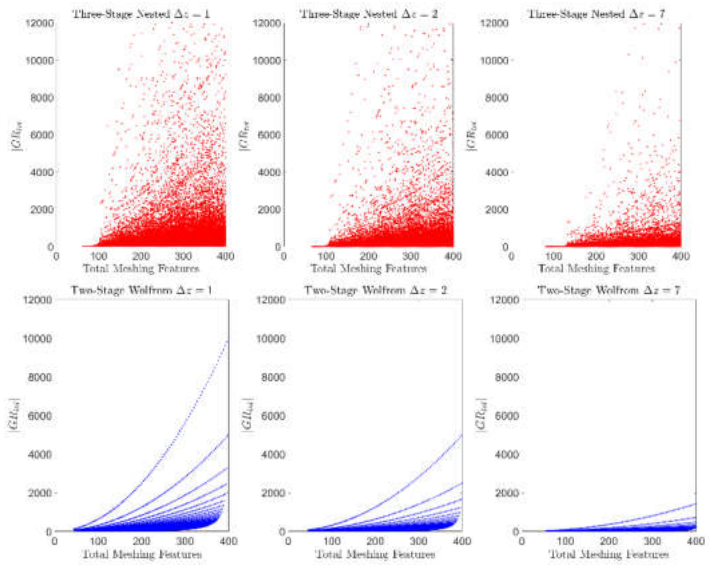

Fig. 4. Difference between Nested and Wolfrom solution in terms of |GRtot| for different Total Meshing Features. Case of $\Delta z = 1$, $\Delta z = 2$, and $\Delta z = 7$.

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P02 - Influence of Geometric Deviations in Rollers and Cycloidal Disk on Power Transmission Performances

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1 Introduction

Cycloidal drives are valued for their low transmission errors and precision, commonly used in robotics and heavy-duty precision machines [1]. Their ability to offer high reduction ratios in compact layouts is appealing for power transmission tasks [2], where efficiency is crucial [3]. In our recent project on construction yard machines, we proposed a Wolfrom-based configuration with fewer large teeth [4,5,6]. This design suits unpredictable overloads and harsh conditions. We aim to compare its sensitivity to dimensional errors against the traditional Mono-stage [4,5], crucial for cost-effective solutions in demanding applications.

2 Materials and Method

2.1 Configurations under Investigation

The cycloidal drive, aimed at construction machinery, targets a 56:1 reduction ratio. Input speed is 1500 rpm from an asynchronous motor, output torque 150 Nm. We examined two designs: (1) Mono-stage, single-stage with "pin-hole" output extraction. (2) Wolfrom, two-stage with fixed roller output extraction.

2.2 Investigation Approach

The benchmark was the condition with nominal dimensions. We considered a positive shift as an error reducing roller radius and tooth height by 0.8 mm. This exceeds "very coarse" precision for Mono-stage (0.5 mm) and falls between "coarse" and "very coarse" for Wolfrom (0.5 and 1 mm, respectively), per ISO 2768. The dimensional error reduces contact points, impacting Input Torque, Torque Ripple, Input Energy, Von Mises Stress.

2.3 Simulation Approach

We utilized the finite element method (FEM). 3D virtual prototypes were parameterized to account for introduced errors in roller radius and cycloids' profile offsets. Virtual prototypes were assembled to manage different system positions, considering angular positions between rollers and input shafts. The material used was steel with an elastic modulus of 210 GPa and a Poisson's coefficient of 0.3. Contact between rollers

and cycloids was modeled with a friction coefficient of 0.05. The applied load was a constant 150 Nm torque, as specified by the machinery manufacturer.

3 Results

In the nominal condition, the Mono-stage torque ranged from 2.21 to 2.78 Nm, increasing to 2.38-2.81 Nm with error. Wolfrom torque ranged from 0.59 to 4.06 Nm in nominal conditions and 0.95 to 3.83 Nm with error. Mono-stage energy consumption was 15.7 J nominally, rising to 16.1 J with error. Wolfrom consumed 12.1 J nominally and 13.4 J with error. Mono-stage stress was 23 N/mm² nominally, rising to 361 N/mm² with error. Wolfrom's first stage stress was 15 N/mm² nominally, increasing to 28 N/mm² with error, and second stage stress was 29 N/mm² nominally, increasing to 40 N/mm² with error.

4 Discussions and Conclusions

The Wolfrom requires less input shaft torque than the Mono-stage, but its torque ripple consistently exceeds the Mono-stage's. Both configurations experience increased average input torque with dimensional errors, though the Mono-stage is less sensitive. Torque ripple decreases for both, with the Wolfrom less affected. Configurations with fewer large teeth show higher average input torque, potentially impacting shaft fatigue. The Wolfrom consumes less energy but absorbs more with coarse precision, though less sensitive than the Mono-stage. It's less sensitive to dimensional errors on contact surfaces, suitable for coarse manufacturing precision.

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P03 - Model based prediction of optimal ropeways for material transport

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Keywords: ropeway, simulation, parallel computing, machine learning

We present our simulation tool “Rope”, a MATLAB program to simulate ropeways for material transport. The latest version runs in parallel on multicore processors allowing fast computation of all relevant geometrical/mechanical quantities required by the standards [1]. With the help of “Rope” we generate a large set of input-output data to support Machine Learning algorithms [2]. Final research goal is the construction of a predictor for a selected cost function [3].

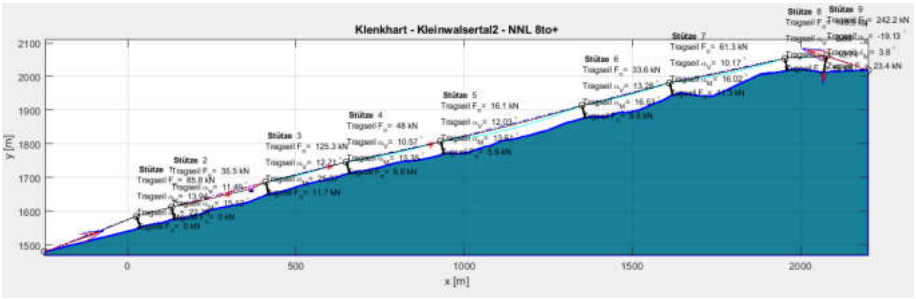

Fig. 1 Overview of the ropeway with support (black) and hauling (cyan) cables, support pressures and mountain profile (interactive output window of “Rope”). Carrier mass 10 ton, cable pretension (valley) 500 kN.

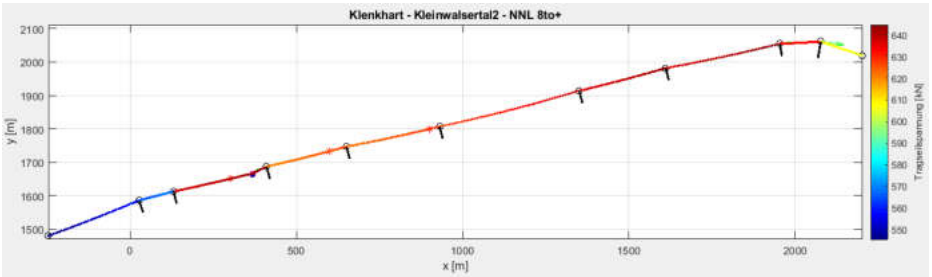

Fig. 2 Support cable tension for carrier position x = 367.56 m (friction resistance at supports included).

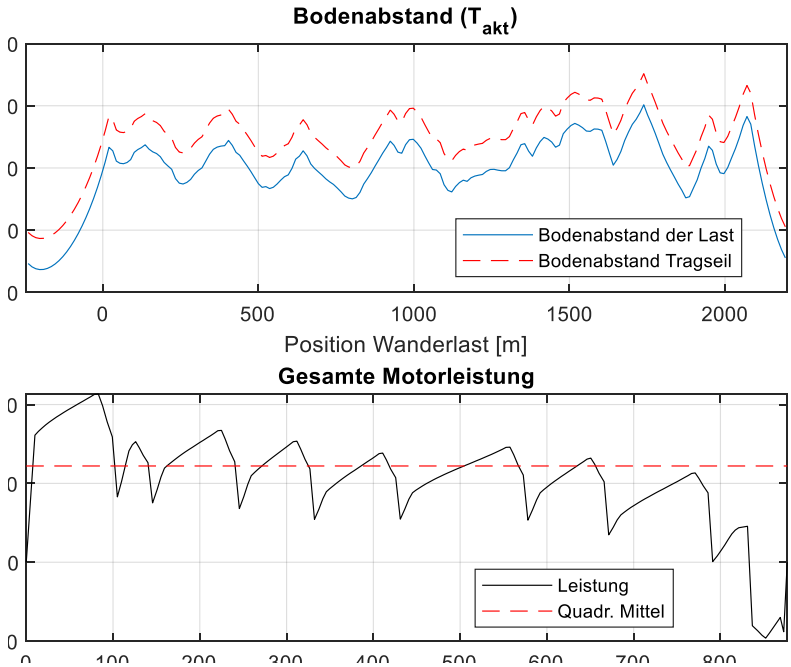

Fig. 3 Carrier – terrain distance and power of the driving engine.

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P04 - Study and Optimization of Main Bearing Lubrication System of a Direct-drive Leitwind Wind Turbine

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Wind is the most sustainable, renewable, and environmentally friendly energy source. There are wind turbines used to extract kinetic energy from the wind and convert it to electricity i.e. direct-drive wind turbines and gearbox wind turbines based on the energy transmission from rotor to the generator.

This research focused on the study and optimization of the main bearing lubrication system of a direct-drive Leitwind wind turbine. Leitwind wind turbines use a direct-drive mechanical transmission system with a single double row tapered roller bearing. Lubrication of the bearing in LW wind turbine is the most critical and important phenomenon in terms of the bearing effective performance and bearing life. The investigation of the functional and performance aspects of the whole bearing system that includes housing, seals, lubrication and cooling circuit is important in order to achieve the above objectives. Non-Newtonian fluid grease is used as lubricant in LW wind turbine. For the improved performance of the main bearing and consequently the turbine, various parameters of the grease should be optimized. These parameters may include its speed, quality, temperature, quantity etc. CFD analysis of the grease within the bearing should be done using different boundary conditions and whole operating range for the optimization of the performance of the main bearing by minimizing areas of possible stagnation and evaluating the lubricant film thickness present and required in the rolling and raceway under idling and run conditions. The optimization of this film thickness should be done based on the results. For effective lubrication, the lubricant quantity, quality, contaminants etc. should be optimized and it can be done by defining sensing and monitoring strategies.

The results obtained from the simulations can be validated by developing the test bed. It can be done the existing wind turbine setup or can be co-design. Different sensors can be installed for acquiring the data.

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