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Editorial

Reliability of Mechatronic Systems and Machine Elements: Testing and Validation

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1. Reliability of Complex Mechatronic Systems

The design of reliable systems is a key challenge in product engineering [1]. Functional reliability means the ability of a system to fulfill its required functionality under specified conditions for a specified period of time [2], ensuring the performance and robustness in operation of a system. In case of complex systems, system reliability is particularly challenging due to strong interactions between the subsystems of a single technical system and its environment. It is therefore important to be aware of future applications of the system in order to take them into account during product development. This can be enabled by application data using integrated sensors and validation, verification and testing (VVT) strategies.

At the system level, investigation of functionality and system modeling as well as simulation techniques are needed. Strategies for the design and operation of mechatronic systems also require optimization methods and control approaches.

On the topic of machine elements, research is needed in sensor technologies and signal processing for machine diagnostics and prognosis. For mechatronic systems, there are approaches for integrating sensors into common machine elements for intelligent mechatronic systems [3,4].

In addition, for the system design and the development of intelligent machine elements, research on VVT methods for complex mechatronic systems is needed. The role of testing and validation is a key activity in industry, but is often underestimated in research. VVT is the knowledge base for successful engineering, both for the next generation of products and for proving the functionality and reliability of the current product design. Therefore, research in the field of VVT is essential to manage the complexity of mechatronic systems in the future. This Special Issue (SI), entitled "Reliability of Mechatronic Systems and Machine Elements: Testing and Validation", makes a valuable contribution to research in this field.

The Special Issue presents original research on reliability strategies and design for reliability, machine elements for intelligent mechatronic systems, and the role of testing and validation during the product development of these systems.

2. Reliability Strategies and Design for Reliability

From the perspective of the design of complex mechatronic systems, there is a need for operating strategies and design methods that force system reliability and robust design. This concerns the topic areas of maintenance strategies, design optimization and control strategies.

With a focus on reliable and robust mechatronic systems, methodical approaches and system modeling for machines and dynamic systems are needed to solve key challenges in product engineering.

This SI includes contributions on preventive maintenance strategies and system reliability, robust and optimized systems, and system control for powertrains and power systems. Uncertainty in manufacturing is considered in some of the contributing articles.

In [5], the selection of a preventive maintenance strategy for industrial machines is proposed based on a multi-criteria decision method. As a result, a multidimensional matrix is shown to determine the best preventive maintenance strategy for the components of a multistage machine.

In [6], a method for the optimization of an additive manufacturing process is shown. The developed method, which is based on a physically informed machine learning approach, helps to reduce the uncertainty of mechanical properties and enhance the quality of printed parts, increasing system reliability.

In [7], an optimization method for brushless direct current (BLDC) motors that takes manufacturing uncertainty into account is presented. The authors demonstrated a reduction in the motor failure rate and performance variation by the proposed method.

In [8], a new control strategy for heating portable fuel cell systems is presented. This study investigates reliable operation under subfreezing conditions and evaluates system efficiency. The results were verified by simulation and experiments on a test bench.

In [9], a new position control of an electrohydraulic actuator (EHA) for use in early product development stages is presented. Based on a multicriteria optimization of the control in simulations, system performance was investigated in simulation and verified on a test bench. The study shows a good prediction of system behavior for the optimized control.

3. Machine Elements for Intelligent Mechatronic Systems

Machine diagnostics and prognosis are key factors for successful and innovative mechatronic products in future. Product innovation requires knowledge about the state of the system. This requires sensor technologies as well as prognostic methods for state estimation.

In order to manufacture intelligent mechatronic systems, sensor integration into system components is especially important. Therefore, research on the prognosis and health prediction of machine elements is necessary. This SI includes contributions to the diagnosis of gears, the investigation of bearing damage, research on the estimation of external excitations and loads, and a scaling approach for drive components.

In [10], the dynamic characteristics of high-contact-ratio spur gear bearing systems are investigated. The vibrational behavior of the system is evaluated based on a proposed dynamic model with tooth spalling defects. The dynamic model is verified by experimental results.

In [11], a scaling model for drive components is investigated. A functional investigation of the drive system was conducted on a X-in-the-Loop test bench based on the coupling of a geometrically scaled drive component and powertrain. This study demonstrates a new method for scaled component tests.

In [12], a model of a two-tooth difference swing-rod movable teeth transmission system is proposed. The influence of external excitation and system load on the system dynamics is investigated. The simulation results were verified by experiments on a test bench.

In [13], a study of electrical bearing damage is presented. The authors propose a metric to evaluate damage progression using surface property data. The experimental data show a suitable approach for quantifying electrical bearing damage.

In [14], the degradation effects of thin-film sensors are investigated. The investigation includes reliability measurements after high loads, which can occur after the application of a critical component load. Based on the results, a sensor data fusion method is proposed. The presented results can be used for system design using these sensors in machine elements.

In [15], sensor integration in an industrial gear is shown. Based on a simulation, a gear modification was proposed and the effect on the load carrying capacity was investigated. The approach shows the trade-off between gear performance and sensor integration used in intelligent systems.

4. The Role of Verification, Validation and Testing of Mechatronic Systems

The papers in this SI present new approaches and related research to address the reliability challenges of mechatronic systems and machine elements. From a product engineering perspective, the role of VVT is a key aspect of reliable and robust systems.

The increasing complexity of mechatronic systems encourages research of new technologies and methods, especially in the field of VVT. In this context, current challenges are related to research on new reliability approaches, but also on machine elements to be used in intelligent mechatronic systems [3,4]. Especially in human–machine systems, interactions with humans and the environment are highly sophisticated [16,17].

Methods and system models are needed to study and simulate the strong interactions between the subsystems of these complex systems. It is important to appreciate the value of VVT activities in research and their relevance for successful product engineering in the future.

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References

1. O'Connor, P.D.T. *Test Engineering: A Concise Guide to Cost-Effective Design, Development and Manufacture*; Wiley: New York, NY, USA, 2001; ISBN 0471498823.
2. Birolini, A. *Reliability Engineering*; Springer: Berlin/Heidelberg, Germany, 2004; ISBN 978-3-662-05411-6.
3. Vorwerk-Handing, G.; Gwosch, T.; Schork, S.; Kirchner, E.; Matthiesen, S. Classification and examples of next generation machine elements. *Forsch Ingenieurwes* **2020**, *84*, 21–32. [CrossRef]
4. Stücheli, M.; Meboldt, M. Mechatronic Machine Elements: On Their Relevance in Cyber-Physical Systems. In *Smart Product Engineering*; Abramovici, M., Stark, R., Eds.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 263–272. ISBN 978-3-642-30816-1.
5. García, F.J.Á.; Salgado, D.R. Analysis of the Influence of Component Type and Operating Condition on the Selection of Preventive Maintenance Strategy in Multistage Industrial Machines: A Case Study. *Machines* **2022**, *10*, 385. [CrossRef]
6. Wenzel, S.; Slomski-Vetter, E.; Melz, T. Optimizing System Reliability in Additive Manufacturing Using Physics-Informed Machine Learning. *Machines* **2022**, *10*, 525. [CrossRef]
7. Jeon, K.; Yoo, D.; Park, J.; Lee, K.-D.; Lee, J.-J.; Kim, C.-W. Reliability-Based Robust Design Optimization for Maximizing the Output Torque of Brushless Direct Current (BLDC) Motors Considering Manufacturing Uncertainty. *Machines* **2022**, *10*, 797. [CrossRef]
8. Zimprich, S.; Dávila-Portals, D.; Matthiesen, S.; Gwosch, T. New Control Strategy for Heating Portable Fuel Cell Power Systems for Energy-Efficient and Reliable Operation. *Machines* **2022**, *10*, 1159. [CrossRef]
9. Dörr, M.; Leitenberger, F.; Wolter, K.; Matthiesen, S.; Gwosch, T. Model-Based Control Design of an EHA Position Control Based on Multicriteria Optimization. *Machines* **2022**, *10*, 1190. [CrossRef]
10. Cheng, Z.; Huang, K.; Xiong, Y.; Sang, M. Dynamic Analysis of a High-Contact-Ratio Spur Gear System with Localized Spalling and Experimental Validation. *Machines* **2022**, *10*, 154. [CrossRef]
11. Steck, M.; Matthiesen, S.; Gwosch, T. Functional Investigation of Geometrically Scaled Drive Components by X-in-the-Loop Testing with Scaled Prototypes. *Machines* **2022**, *10*, 165. [CrossRef]
12. Wei, R.; Yi, Y.; Wu, M.; Chen, M.; Jin, H. Analysis of Load Inhomogeneity of Two-Tooth Difference Swing-Rod Movable Teeth Transmission System under External Excitation. *Machines* **2022**, *10*, 502. [CrossRef]
13. Harder, A.; Zaiat, A.; Becker-Dombrowsky, F.M.; Puchtler, S.; Kirchner, E. Investigation of the Voltage-Induced Damage Progression on the Raceway Surfaces of Thrust Ball Bearings. *Machines* **2022**, *10*, 832. [CrossRef]
14. Ottermann, R.; Steppeler, T.; Dencker, F.; Wurz, M.C. Degeneration Effects of Thin-Film Sensors after Critical Load Conditions of Machine Components. *Machines* **2022**, *10*, 870. [CrossRef]
15. Bonaiti, L.; Knoll, E.; Otto, M.; Gorla, C.; Stahl, K. The Effect of Sensor Integration on the Load Carrying Capacity of Gears. *Machines* **2022**, *10*, 888. [CrossRef]

16. Amaya-Toral, R.M.; Piña-Monarrez, M.R.; Reyes-Martínez, R.M.; de La Riva-Rodríguez, J.; Poblano-Ojinaga, E.R.; Sánchez-Leal, J.; Arredondo-Soto, K.C. Human–Machine Systems Reliability: A Series–Parallel Approach for Evaluation and Improvement in the Field of Machine Tools. *Appl. Sci.* **2022**, *12*, 1681. [CrossRef]
17. Gwosch, T.; Dörr, M.; Matthiesen, S. Modeling of Human-Machine Systems for System Reliability Testing: Investigation of the User Impact on the Load of the Machine. In Proceedings of the 2021 Stuttgarter Symposium für Produktentwicklung, SSP 2021, Stuttgart, Germany, 20 May 2021; Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO: Stuttgart, Germany, 2021; pp. 1–10.