SUBPROJECT 11: Methodical development of complex deformable active multi-matrix composite (MMC) components

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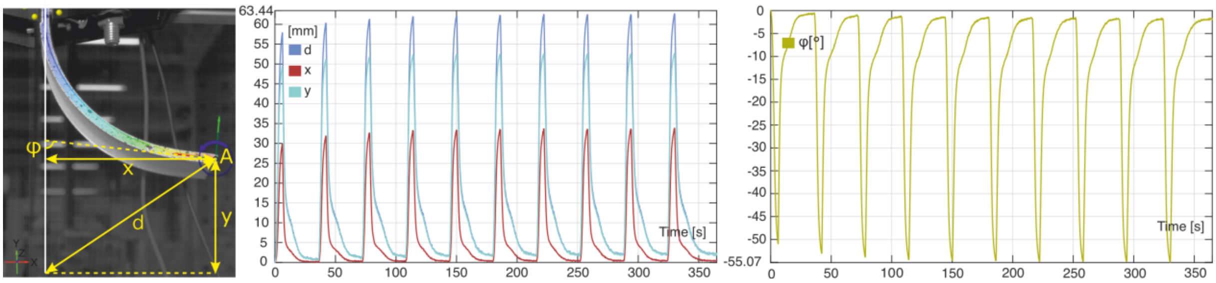
Motivation

Multifunctional smart materials capable of interacting directly with humans are showing remarkable promise in a variety of fields, including medical treatment, bionics, robotics, automation technology and aerospace applications. Active multi-matrix composites (MMCs) stand out for their light weight, compact structure, excellent deformability, adaptability to changing environments, and seamless movement. On the one hand, by integrating functional materials such as magnetic particles, conductive particles and dielectric materials, MMCs are able to perform complex functions without the need for subsequent actuators and sensors. On the other hand, MMCs possess the inherent capability to achieve customized mechanical properties through local stiffness adjustments to meet the requirements of multi-dimensional motion for specific tasks. Nevertheless, the comprehensive characterization methodology for MMCs and the systematic process from design to production are still in the development stage and require further research and improvement.

State of the art and previous research

Within the 1st cohort of the RTG 2430, an optimization algorithm was developed and integrated with finite element method (FEM) to create an environment for designing path-guided compliant mechanisms [1]. The effectiveness of this environment was validated through the fabrication of prototypes using 3D printing technology. The technology demonstrated significant advantages in rapid prototyping, custom design, and the manufacturing of complex structures and high-resolution parts, which led to its continued use in the 2nd cohort for the production of unimorph dielectric elastomer actuators capable of high-frequency deformation and shape memory alloy wire-driven flexible actuators capable of transmitting increased forces [2]. Material- and structure-based anisotropic effects was employed to achieve the transformation from planar stimulation to spatial movement through coupling within the actuator strain tensor, thus achieving 2.5D deformation. Comprehensive characterization of actuators with different configurations was completed, and theoretical models were developed to describe their deformation behavior [3], which significantly outperformed finite element models in terms of computational speed. Furthermore, an innovative method for synthesis of compliant mechanism with active MMC component was developed by combining similarity transformation theory, enabling point guidance for both closed and open-chain active compliant mechanisms. This method is not only scalable to the design of 3D motion mechanisms but also integrable with optimization algorithms and artificial intelligence models to develop a software environment that supports rapid design, meeting the needs for multi-point guidance and path generation. This provides robust support for engineers in the early stages of developing. Additionally, leveraging the inherent advantages of composite materials, strain sensors were integrated to achieve closed-loop control of their motion behavior [4]. The controller was further improved to enhance system stability and response speed [5, 6].



Experimental results of a SMA-driven MMC component under cyclic activation

Scientific questions and project objectives

The 3rd cohort will be devoted to the methodical development and realization of complex robotic structures. In order to achieve this goal, it is necessary to extend computational models to 3D deformations and to built-up the dynamical equations of a system with MMC components. Based on the dynamic model, controllers for such systems will be developed, which will allow the individual active elements of the system to cooperate and interact with each other for performing specific motion tasks. In addition, 3D printing and mechanism synthesis methods will be extended to magneto-active elastomers (MAE). Therefore, magnetizable fibers or chain-like magnetizable particles integrated into 3D printing filaments will be investigate to fabricate MMC components. The distribution of magnetizable particles will be adjusted strategically, and their mechanical anisotropy when exposed to a magnetic field will be characterized comprehensively. The effects of the concentration of filler material, the magnitude, and direction of the magnetic field on the deformation behavior will be investigated to construct a constitutive model. Based on this, the magneto-mechanical behavior of the MMC components will be modeled and a synthesis methodology for compliant mechanisms with MAE components will be developed, leveraging the computational and design models from the previous two cohorts. Furthermore, to completely automate the entire iterative design and manufacturing process, an interface between the computational environment and CAM software will be developed, along with a Graphical User Interface (GUI).

The development of controllers for 3D-deformable MMC-systems will be performed in cooperation with SP 9. Furthermore, 3D-printing and curing of novel functionally elastomers as well as the investigation of magnetizable fibers or chain-like magnetizable particles integrated into 3D printing filaments will be investigated in close interaction to SP 3 and SP 4.

References

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