Coreless filament winding of lightweight structures: digital path optimization and automatic robot programming

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Abstract

Extremely lightweight components can be produced by coreless filament winding (CFW). CFW is a manufacturing technique in which filaments are placed to approximate the load paths, typically resulting in lattice structures. This allows a high specific stiffness to be achieved with a minimum amount of material, which matters where structural performance and low mass are equally required. Typical fields of application are lightweight vehicle and aircraft structures, robot components and load-bearing architectural elements.
The development of CFW structures differs substantially from conventional design and manufacturing techniques. Because of the anisotropic material behavior, the resulting stresses cannot be estimated easily. In addition, manual production is time-consuming and therefore too cost-intensive for series production. Both the load paths and the constraints of the winding process therefore have to be integrated into the development process. To achieve this, a digital, modular process chain was developed in a publicly funded project, ranging from the simulation-based design and optimization of a component to its automated production by a robot. DITF developed three modules of this process chain: the optimization of the winding sequence, the generation of the winding path and the generation of the robot code. DITF also implemented a data format that enables a consistent exchange of information across all modules.

The winding path has to meet several requirements. It must be traversable in a single continuous run and must not pass through filaments that have already been placed. For 3D structures, the subsequent winding pins must remain accessible and must not be covered by previously placed filaments. In addition, the change in direction at each winding pin should be kept as small as possible, and the filaments should be distributed evenly across the pins.

To meet these requirements, an algorithm combining graph theory with an evaluation scheme was developed. It works iteratively and rates each step based on the previous steps. A second module derives the winding path from this optimized sequence and the component geometry. A final module translates the path into robot code for the specific robot type. So far, it has been implemented for two robot languages: G-code and KUKA Robot Language (KRL). All modules exchange their data via the newly developed data format.

The entire process chain was validated on a generic component, which was designed, optimized, converted into a winding path and finally wound by the robot.

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