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High-field laser patterned HTS magnets enabling compact fusion reactors

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Magnetic nuclear fusion reactors such as tokamaks and stellarators rely on superconducting coils (also called magnets) to confine and shape the plasma in which the fusion reactions occur. Stellarators are fusion devices based on three-dimensional plasma shapes which enable steady state and more stable operations compared with tokamaks. Nevertheless, the complex stellarator plasma shape demands extremely sophisticated coil designs, optimized to achieve the target magnetic configuration with high precision. In addition, field strength in this kind of reactor also plays a major role in fusion performance and economic viability. Indeed, by increasing the field strength, one can reduce the plasma volume and thus achieve more compact reactors. The highly specialized technical expertise as well as the far-reaching requirements in human and material resources necessary to design, manufacture and assembly superconducting magnets combining high field strengths and high precision tend to delay the development of economically viable fusion reactors. For this reason, the development of small-scale steady state fusion reactors is intimately dependent on technological innovations in superconducting magnets.

Renaissance Fusion is a nuclear fusion start-up developing a novel technology for High Temperature Superconductor (HTS) coils applied to stellarators. The design, manufacturing and assembly of these coils is drastically facilitated by (1) simplified coil-winding-surfaces and (2) wide laser patterned HTS foils. Indeed, in order to obtain the current distribution necessary to produce the required stellarator plasma-confining magnetic fields, laser-ablated grooves will geometrically constrain the currents flowing through the superconducting coils.

This work addresses the development of a computation design tool that optimizes grooving patterns necessary to produce a specific target field. As a first step towards reproducing a stellarator magnetic configuration, our grooving pattern design tool was applied to axisymmetric fields within circular cylindrical open magnets. A least squares resolution combined with Tikhonov regularization was implemented to solve the inverse problem. Two reduced-scale test cases are presented: a uniform MRI field and a gyrotron field profile. For both cases, the grooved conductor reproduced the target field profile with the required precision, demonstrating the potential of this approach for simplifying the design of complex magnets.

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