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M1Po3B-01: Fatigue analysis of Stirling cryocooler flexure springs for long space mission lifetime

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Cryocoolers are used in space instruments to cool detectors and superconducting devices to cryogenic temperatures. Inside a cryocooler, a flexure spring is used to ensure the cryocooler piston is axially free to move but is radially restricted, preventing off-axes forces that could cause piston contact with the sides of the cylinder, which is the primary cause for failure in a space cryocooler. Given that the flexure spring is mission-critical to the cryocooler operation yet prone to failure, its lifetime can, in effect, determine the lifetime of the space mission itself. By extending the life of the flexure spring, space missions can be extended and pose longer reliability. This study investigated various key spring design parameters to assess their impact on the operation of a spiral flexure spring built with AISI 1045 Steel, which consists of spring arms in a characteristic spiral shape. These parameters include the number of spiral spring arms, spring design, and spring thickness. Results show that the lowest maximum stress is observed at lower spring thickness values, moderate arm numbers, and teardrop sizes that vary for different arm numbers. Based on these results, an optimal design is proposed that maximizes flexure spring lifetime while operating at a resonant frequency in continuous oscillatory motion to reduce the input power requirements and increase the lifetime of flexure springs for long-lifetime space cryocoolers. In this design, the design parameters are adjusted for optimal flexibility as a proof of concept, with additional designs inspired by origami proposed. In the latter design, a longer lifetime is demonstrated, extending to the lifespan of space missions that rely on cryocooler operation.

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