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Fri-Mo-Po.09-04: Design of a Distributed Coil Array Magnet System for Electromagnetic Stress Relief in Large Aluminum Alloy Rings

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Large aluminum alloy rings are vital components in wind turbine and high-speed train, serving as bearing rings, transition rings, and reinforcing structures. The structural stability and mechanical properties of these rings are critical to ensuring assembly precision and safety performance of these systems. However, the manufacturing process of large aluminum alloys rings inevitably introduce residual stress due to uneven thermal and mechanical loading during large-scale forming. These residual stress can adversely affects both the mechanical strength and dimensional accuracy of the components.

Common methods for eliminating residual stress include mechanical and energy-based approaches. Mechanical techniques rely on external forces exceeding the material's yield strength to induce plastic deformation and relieve residual stress. But these techniques risk surface damage and can introduce new residual stresses. Energy-based approaches reduce lattice distortions by applying external energy to restore atomic equilibrium and promote uniform dislocation distribution. However, these methods often lead to grain coarsening, compromising component strength and dimensional accuracy. In our recent research, a pulsed magnet coaxial aligned with an aluminum alloy ring was employed to generate a Pulsed High Magnetic Field (PHMF), inducing plastic deformation and significantly reducing residual stress without compromising material strength. This method offers advantages such as uniform force application and non-contact operation. However, scaling the method to larger rings introduces challenges, including increased manufacturing complexity and higher costs for single-coil magnets.

To address these limitations, this study proposes a novel magnet topology based on a distributed coil array. The system consists of 24 pancake coils uniformly arranged along the inner circumference of the ring. Each coil generates localized electromagnetic force, enabling precise and uniform deformation. By combining circumferential rotation and multiple discharge cycles, high uniformity in ring expansion is achieved. Finite element simulations using LS-DYNA, incorporating partial electromagnetic modeling and explicit-implicit coupling, were conducted to evaluate system behavior. Systematic investigations of the magnet's structural parameters and coil distribution informed the design of the electromagnetic system and discharge processes. Simulation results demonstrate that when the total energy of the 24 coils per discharge reaches 4.5 MJ, eight discharge cycles induce an average plastic strain of 1.20%, with a maximum deviation of 0.16% between the highest and lowest strain values. This level of plastic strain effectively eliminates residual stress. The findings highlight that the coil array design reduces production costs, minimizes operational risks, enhances system flexibility, and extends service life.

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