



Direct cooling technology in electrical machines

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Abstract

Direct liquid cooling provides an efficient alternative to conventional air-cooling methods for electrical machines, particularly under high thermal loads or in confined spaces where airflow is limited. Compared to air, dielectric oils offer higher specific heat capacity and enhanced heat transfer, enabling rapid dissipation of heat from critical regions such as stator windings and end coils. Direct liquid cooling reduces thermal resistance by providing localized coolant contact via spray jets or impingement streams, improving cooling performance where indirect methods are insufficient. Furthermore, external placement of system components, including pumps, heat exchangers, and filters, allows compact motor design and efficient heat extraction, even in restricted environments such as automotive powertrains. Active control of pump flow, valves, and fans enables adaptive thermal management, minimizing energy consumption and noise under variable loads. Encapsulation within a closed circuit also enhances protection against dust and contaminants. However, these benefits come at the cost of increased system complexity, maintenance requirements, and potential coolant handling challenges, particularly at low temperatures where preheating may be required. Consequently, direct liquid cooling is most suitable for high-performance applications demanding high power density, efficient heat removal, and compact packaging, including electric vehicles, motorsport drives, and high-speed industrial machines. Future developments may focus on system integration, hybrid cooling approaches, and optimized winding designs, such as hairpin coils, to further improve thermal performance and reliability.

Keywords

Direct liquid cooling , Electric machines, Heat transfer coefficient