Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

A NUMERICAL ANALYSIS OF HEAT TRANSFER AND HYDRODYNAMIC PERFORMANCE IN ELECTRIC MOTORS USING TANGENTIAL JETS

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ABSTRACT

Effective thermal management in electric motors requires cooling strategies that mitigate stator temperature non-uniformities, a challenge inadequately addressed by axial jet impingement due to uneven oil distribution. To address this issue, this study numerically investigates the potential of tangential jet impingement as a better alternative. The focus is on offset unsubmerged jets in a confined rotating disk system, modeled after electric motor components. In this setup, the rotor and stator are represented as rotating and stationary parts, respectively. To accurately capture the flow behavior, the simulations use a three-dimensional unsteady Reynolds-Averaged Navier-Stokes approach with the SST $k-\omega$ turbulence model. The Volume of Fluid method and moving mesh rotation are employed to analyze two-phase flow dynamics across a range of rotational Reynolds numbers ($Re_{\omega} = 1 \times 10^5 - 3.7 \times 10^6$). The tangential jets are positioned at 70% of the disk radius, with a nozzle diameter of 1.5 mm, ensuring targeted oil delivery to the stator surface. The results show that tangential jets provide better stator cooling compared to axial jets. The highest heat transfer occurs at a jet-to-rotor velocity ratio of 1 ($Re_{\omega} = 6.1 \times 10^5$), improving thermal performance by 36%. This improvement is due to helical impingement and enhanced oil-air mixing, which promote efficient heat dissipation. Additionally, this configuration reduces temperature variations in the stator, even at lower flow rates. Increasing the speed up to $Re_{\omega} = 2 \times 10^6$ enhances heat transfer by up to 30%, but exceeding this limit ($Re_{\omega} = 3.7 \times 10^6$) reduces cooling efficiency by 6%. This decline occurs because excessive rotation reduces oil contact with the critical rotor-stator interfaces, limiting heat removal. Beyond thermal performance, tangential jets also improve hydrodynamic efficiency. Compared to axial jets, they reduce drag losses by 23% ($Re_{\omega} = 6.1 \times 10^5$) and pressure losses by 15% ($Re_{\omega} = 3.7 \times 10^6$). Their alignment with the rotating flow minimizes energy losses, making them a more efficient cooling solution. However, pressure spikes near jet exits indicate a need for optimized outlet designs to further enhance performance. Overall, a mid-range $Re_{\omega} = 2 \times 10^6$ offers the best balance between oil distribution and cooling efficiency, making tangential jets ideal for stator-dominant thermal management under constrained flow rates. This study highlights their effectiveness in mitigating stator overheating and provides a foundation for future research on complex geometries and transient thermal loads for real-world motor applications.