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Heat Transfer Inside an Electric Motor

Ahmed M. Teamah[12], Mohamed S. Hamed[1]
[1]Thermal Processing Laboratory, Department of Mechanical Engineering, McMaster University
1280 Main Street West, Hamilton, Ontario, Canada
[2]Corresponding author: teamaha@mcmaster.ca

Abstract **-** Convection heat transfer from an axial air flow inside the gap between the rotor and the stator of a four-pole surface permanent magnet (SPM) electric motor has been investigated. All surfaces considered smooth with heat is being generated within the rotor while the stator is considered insulated. This study has been carried out numerically using ANSYS-CFX. The effect of the axial flow and rotational speed on the average Nusselt number has been investigated in terms of the axial and rotational Reynolds numbers in the range of 2140- 6420 and 1750- 27000, respectively. Numerical results have been validated using experimental data and found in reasonable agreement. Results show that the effect of the axial Reynolds number is more dominant than that of the rotational Reynolds number.

Keywords**:** Heat transfer, SPM Motors, Taylor Couette Poiseuille flow, Rotating concentric cylinders.

1. Introduction and Literature Review

Electric motors generate heat and need to be cooled down to avoid overheating. The cooling of a Surface Permanent Magnet (SPM) electric motor is provided by an axial air flow passing through a slotted annular gab. The shape of such gab is shown in Fig. 1. The required amount of axial air flow to provide sufficient cooling as a function of the motor rotational speed must be determined.

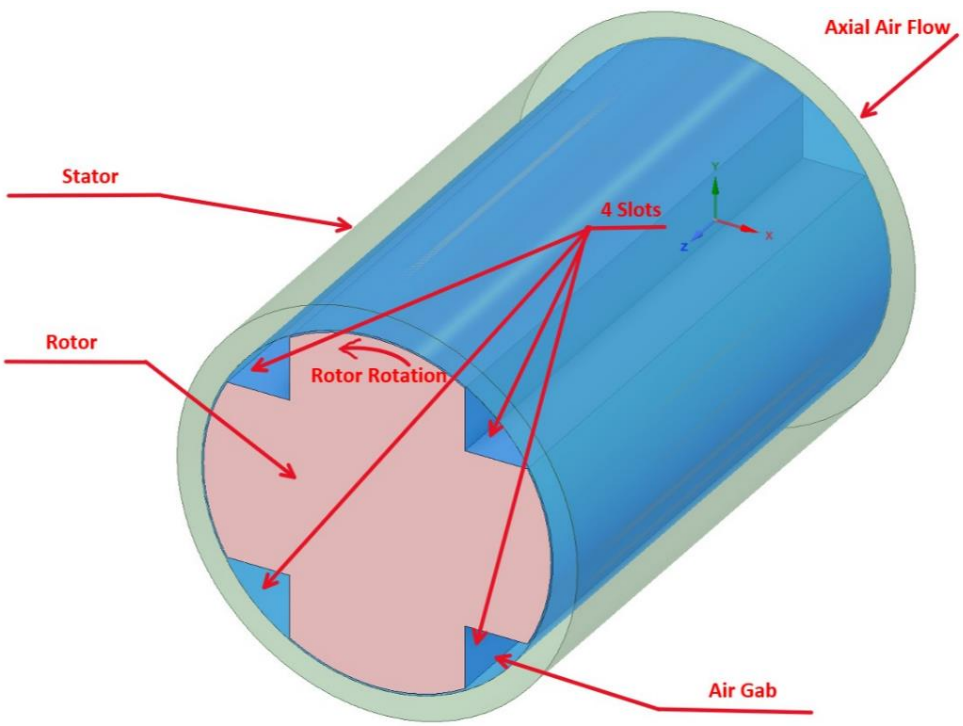

Fig. 1: Air gab inside the electric motor.

Many researchers have investigated the cooling of electric motors. In [1], [2], [3] and [4] focused on the heat transfer and fluid flow of a Taylor-Couette flow developed inside electric motors. A review of flow between concentric cylinders was carried out by [5]. [6] investigated flow instabilities that occur in the flow between rotating cylinders. [7] studied the effect of the gab entrance region and showed that it is similar to the entrance region of a pipe or a duct. [8] studied the effect of adding slots to the motor stator on the rate of heat transfer to the flow in the annular gap. They showed that these slots have almost no effect on the rate of heat transfer. To the best of the authors' knowledge, there has not been any studies that considered the presence of slotted rotor with the working operating range of Reynolds number reaching 27000 for the rotational Reynolds number.

2. Problem Definition

The problem of interest involves fluid flow and heat transfer within an annular space between a rotor and a stator of an electric motor in the presence of an axial air flow passing through the rotor slots as shown in Fig. 2 with a length of 500 mm. The inner rotating cylinder (i.e., the rotor) is subjected to a uniform heat flux of 500 W/m^2. The outer cylinder (i.e., the stator) is fixed and insulated. All walls are considered smooth. Radiation heat transfer has been neglected. The radius ratio, (Rri/Rro), equals to 0.65.

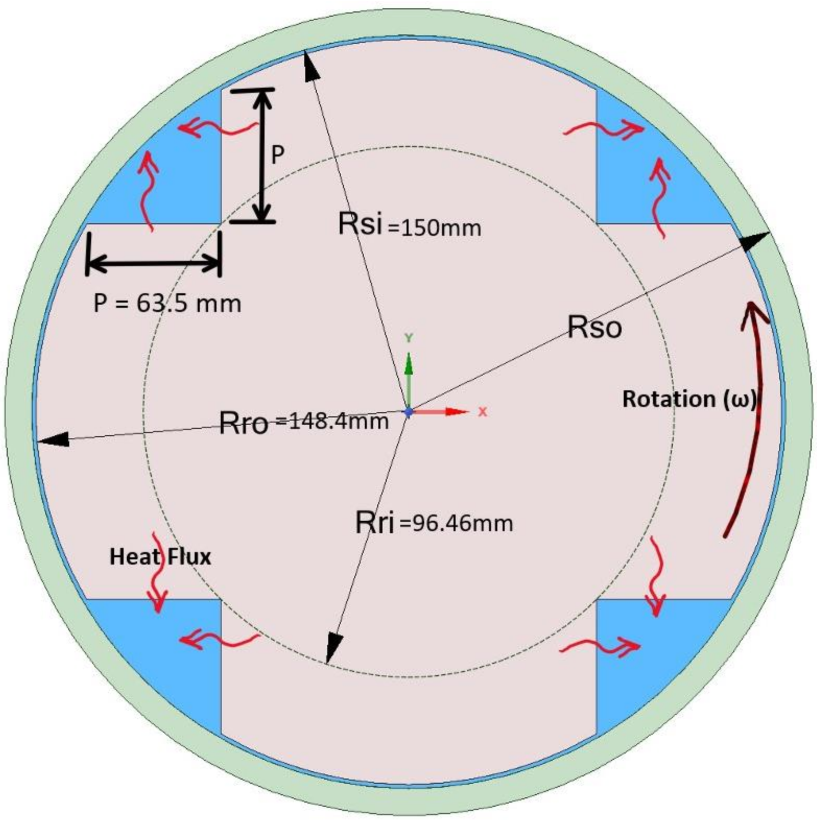

Fig. 2: Schematic diagram of the present Problem

3. Mathematical Model

Flow and heat transfer within the present problem have been simulated using ANSYS-CFX. The governing equations of mass, momentum, and energy are solved as referenced in [9]. The Shear stress transport (SST) turbulence model has been used in this work to capture the turbulence in the moving air flow. The boundary conditions for the problem are of insulated stator with no heat flux and constant heat flux over the rotor surface of 500 W/m^2.

The definition of axial Reynolds number (Re_a), rotational Reynolds number (Re_r), Nusselt number (Nu) and hydraulic diameter (D_h) are in the following equations:

$$Re_a = \frac{V_a * D_h}{\nu_{air}} \tag{1}$$

$$Re_r = \frac{\omega * Rro * D_h}{\nu_{air}} \tag{2}$$

$$Nu = \frac{h * D_h}{K_{air}} \tag{3}$$

$$D_h = \frac{P}{2 + \sqrt{2}} \tag{4}$$

The axial velocity (V_a) is the average air velocity through the slots. Kinematic viscosity of air (ν_{air}) and thermal conductivity of air (K_{air}) are calculated at the average temperature across the domain. The heat transfer coefficient of air inside the gab is referred to by (h). The angular velocity of the rotor is identified by (ω). Gab width (P) is defined as shown in Fig. 2.

4. Validation of Numerical Results

Validation of the present numerical results has been carried out using experimental data published in [10]. In [10] a study of axial air flow inside a slotted rotor of a SPM electric motor. The hydraulic diameter used was 15.8 mm, the radius ratio was kept fixed at 0.75 and the axial flow Reynolds number was 4280. The rotational Reynolds number was varied from 1750 to 10000. The maximum deviation between the present numerical results and the experimental data reported in [10] is about 8%, as illustrated in Fig. 3.

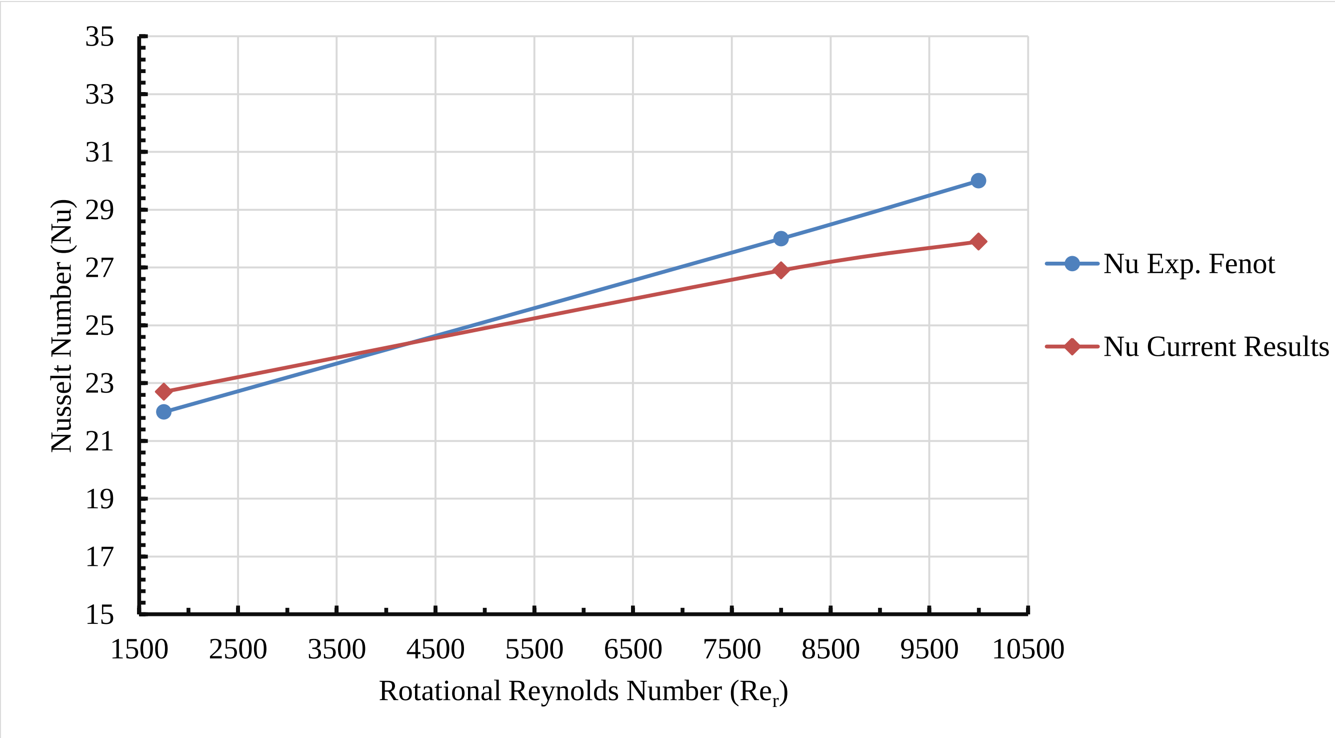

Fig. 3: Validation with experimental data reported in [10] at Re_a = 4280

5. Results and discussion

The parameters investigated in the present study are the axial Reynolds number (Re_a) and the rotational Reynolds number (Re_r) in the range of $2.14x10^3$ to $6.42x10^3$ and $1.75x10^3$ to $2.7x10^4$, respectively. The axial Reynolds number and the rotational Reynolds numbers are defined in equations (8) and (9). The effect of Re_r and Re_a on the average Nusselt number has been investigated.

5.1. Effect of rotational Reynolds number on the average Nusselt number

Fig. 4 shows the effect of the rotational Reynolds number on the average Nusselt number at constant axial Reynolds number of 6420. Results indicate that increasing the rotor rotational speed improves the rate of heat transfer within the gab, hence it enhances the cooling of the SPM motor. The results showed that the rate of increase in Nusselt number decreased somewhat at Re_r = 8000, observation of it is still under investigation.

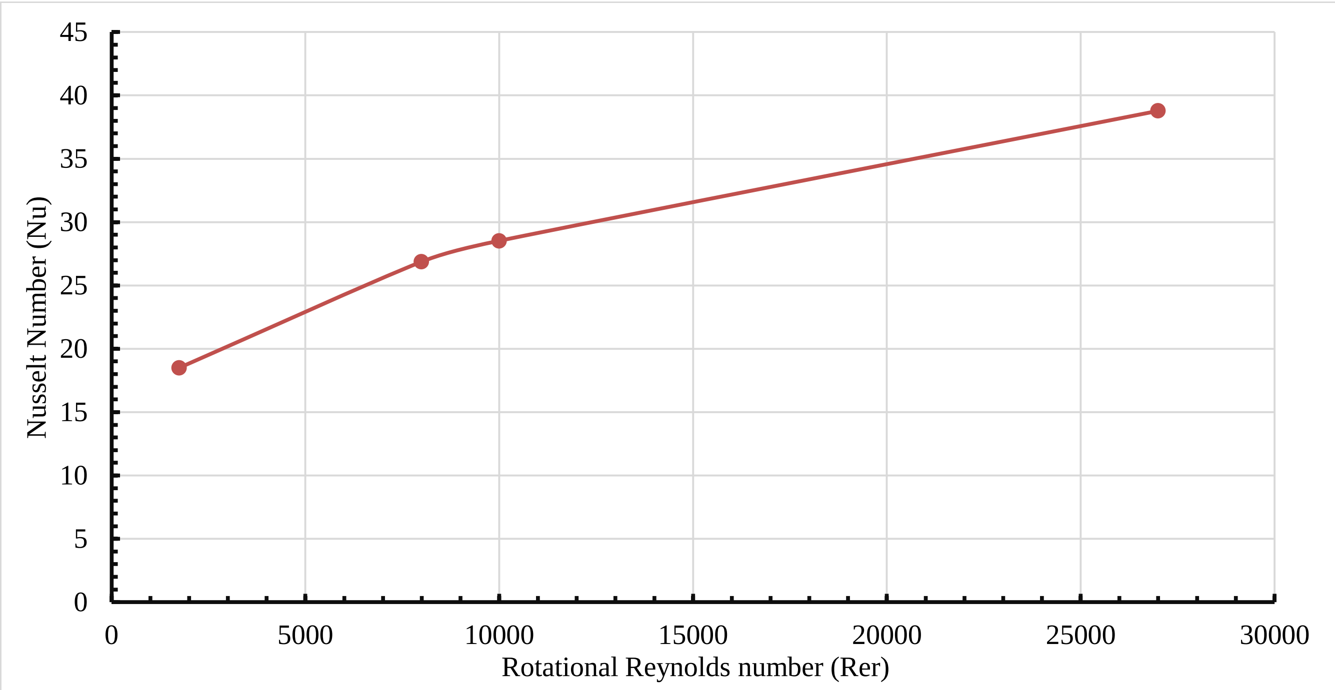

Fig. 4: Effect of rotational Reynolds number on average Nusselt number at Rea = 6420

5.2. Effect of axial Reynolds number on the average Nusselt number

Fig. 5 shows the effect of the axial Reynolds number on the average Nusselt number. Increasing Re_a resulted in an increase of Nu at all values of Re_a considered in this study. However, results suggest that the effect of Re_a on the rate of heat transfer is more pronounced than the effect of Re_r. Therefore, motor cooling is significantly improved by increasing the axial air velocity that the rotor speed. The increase of the rotational speed results in more circulation of the hot air inside the gap (i.e., the slots).

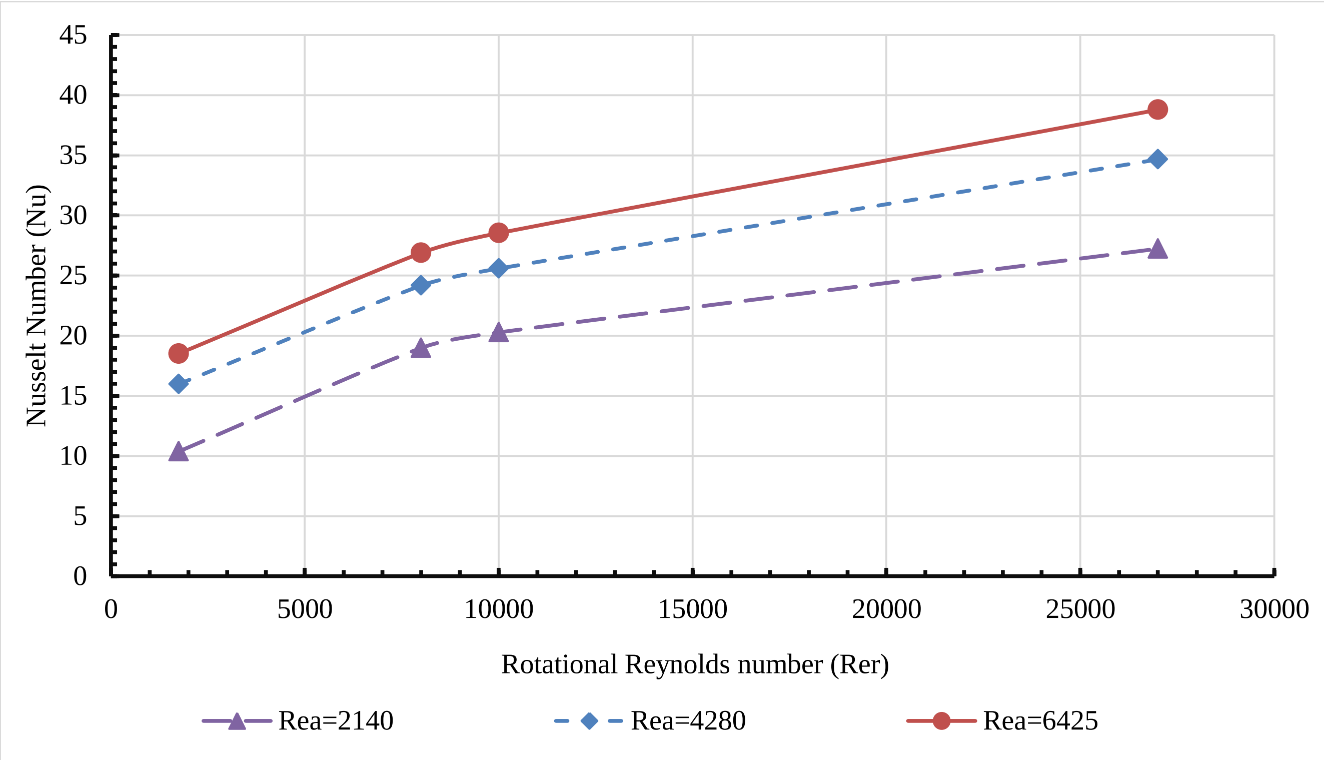

Fig. 5: Effect of rotational and axial Reynolds number on average Nusselt number

6. Conclusion

The effect of the rotor rotational speed and the axial air velocity on the cooling of an SPM motor has been investigated. Results showed that increasing the rotor rotational speed and the axial air velocity enhances motor cooling. However, the effect of the axial air velocity on motor cooling is more pronounced than the effect of the rotational speed on the slotted rotor.

Acknowledgements

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References

[1] A. Fasquelle, J. Le Besnerais, S. Harmand, M. Hecquet, S. Brisset, P. Brochet, and A. Randria, "Coupled electromagnetic acoustic and thermal-flow modeling of an induction motor of railway traction," *Applied Thermal Engineering*, vol. 30, pp. 2788-2795, 12/01 2010.

[2] Y. Huai, R. Melnik, and P. Thøgersen, "Computational analysis of temperature rise phenomena in electric induction motors," *Applied Thermal Engineering - APPL THERM ENG*, vol. 23, 05/01 2003.

[3] Z. Kolondzovski, A. Belahcen, and A. Arkkio, "Multiphysics thermal design of a high-speed permanent-magnet machine," *Applied Thermal Engineering - APPL THERM ENG*, vol. 29, pp. 2693-2700, 09/01 2009.

[4] C.-H. Huang and H.-C. Lo, "A three-dimensional inverse problem in estimating the internal heat flux of housing for high speed motors," *Applied Thermal Engineering - APPL THERM ENG*, vol. 26, pp. 1515-1529, 10/01 2006.

[5] M. Fénot, Y. Bertin, E. Dorignac, and G. Lalizel, "A review of heat transfer between concentric rotating cylinders with or without axial flow," *International Journal of Thermal Sciences - INT J THERM SCI*, vol. 50, pp. 1138-1155, 07/01 2011.

[6] G. I. Taylor, "Stability of Viscous Liquid Contained Between Two Rotating Cylinders," *Philosophical Transactions of the Royal Society of London*, vol. 223, pp. 289-343, 01/01 1923.
[7] M. Molki, K. N. Astill, and E. Leal, "Convective heat-mass transfer in the entrance region of a concentric annulus having a rotating inner cylinder," *International Journal of Heat and Fluid Flow*, vol. 11, pp. 120–128, 06/01 1990.
[8] C. Gazley, "Heat transfer characteristics of the rotational and axial flow between concentric cylinders," *Trans. ASME*, vol. 80, pp. 79-90, 01/01 1958.
[9] C. J. S. t. g. ANSYS, ANSYS, "Release 12.0 User's guide," 2009.
[10] M. Fénot, E. Dorignac, A. Giret, and G. Lalizel, "Convective heat transfer in the entry region of an annular channel with slotted rotating inner cylinder," *Applied Thermal Engineering*, vol. 54, pp. 345–358, 05/14 2013.