# AERODYNAMIC CHARACTERISTICS OF A COOLING FAN IN A LOW-VOLTAGE ELECTRIC MOTOR

Jae-Min PARK[1], Man-Woong HEO[1], Kwang-Yong KIM[1], Hyeon-Seok SHIM[1], Jang-Un CHOI[2], Joon-Yeob LEE [2]

[1] *Department of Mechanical Engineering, Inha University, 100 Inha-Ro, Nam-Gu, Incheon, Republic of Korea*

[2] *Electrical Engineering Research Dept., Hyundai Heavy Industries Co., Ltd., 17-10 Mabuk-Ro, 240beon-Gil, Giheung-Gu, Yongin-Si, Gyeonggi-Do, Republic of Korea*

## SUMMARY

In this paper, the aerodynamic characteristics of a cooling fan in a low-voltage electric motor were numerically investigated by solving three-dimensional Reynolds-Averaged Navier-Stokes equations. The k-ε model was used for analysis of turbulence. The finite volume method and unstructured tetrahedral grids were used in the numerical analysis. A parametric study was performed for the aerodynamic performance, and the parameters related to the geometry of the blade and fan casing were selected for the study. It was found that mass flow rate through the cooling fan can be increased by controlling the flow separation in blade passage and fan casing.

## INTRODUCTION

Low-voltage electric motors are widely used as important power sources in various industries. Because cooling fans for these motors need to be operated bi-directionally, radial blade centrifugal fans are widely applied to the cooling of the electric motors. Recent legislation detailing minimum energy performance standards for energy using products have been introduced worldwide, and manufacturers have responded by investigating methods for reducing energy consumption of their products. In order to meet this condition, the reductions in aerodynamic loss in cooling passage and thermal instability caused by heat generation, are required to be improved in order to enhance the motor performance.

There have been some experimental and numerical investigations of cooling fans in electric motors. Grimes et al. [1] experimentally and numerically studied the flow induced by a motor cooling fan of axial type. They measured radial and tangential velocity components near the inlet of the cooling fan to investigate the effect of blockages on the performance of the cooling fan. Li [2] experimentally investigated cooling performance of a magnet electric motor with a variation of geometry of centrifugal impeller. Walsh et al. [3] conducted experiments to evaluate the effects of inlet cover design on cooling performance of the electronic portable devices. And, Chang et al. [4] investigated thermal performance of a large scale motor with guide vanes in the casing, and suggested the optimum distance between guide vanes and fan blades to minimize the leakage flow.

As mentioned above, some researchers investigated aerodynamic characteristics of motor cooling fans. However, systematic aerodynamic analysis has not yet been performed for electric motor with bi-directional cooling fan. In this work, the effects of the shapes of fan blades and casing on aerodynamic performance of a motor cooling fan, have been investigated based on three-dimensional Reynolds-Averaged Navier-Stokes (RANS) analysis.

## NUMERICAL ANALYSIS

In this study, aerodynamic characteristics of a cooling fan in a low-voltage electric motor were analyzed by solving three-dimensional RANS equations with the k-ε turbulence model. **Figure 1** shows the computational domain with the reference cooling fan in a low-voltage electric motor. The whole flow domain of the cooling fan was considered as the computational domain for the numerical analysis. This computational domain includes a rotating impeller domain and two stationary domains (flow domains in inlet duct and on motor body). To solve three-dimensional RANS equations, the commercial CFD code, ANSYS-CFX 15.0 [5], was used by employing an unstructured grid system. And, the k-ε model was used as turbulence closure. The first grid points from the wall were adjusted to keep y+ >20 as shown in **Fig. 2**.

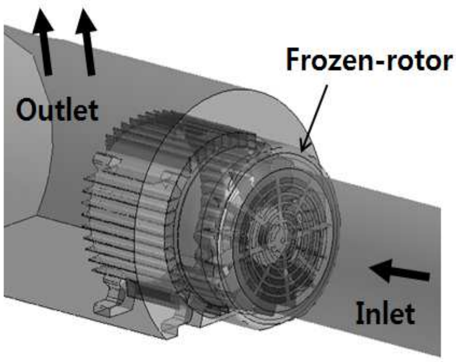



*Figure 1: Computational domain with reference motor cooling fan*

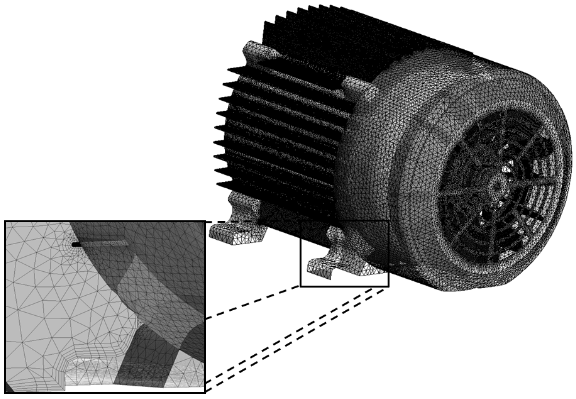


*Figure 2: Structure of the grid system*

The working fluid was considered as an air at 25°C and the total and static pressures were set at inlet and outlet boundaries for steady-state simulation, respectively. The surfaces of the fan blades and motor body were considered no-slip walls. The frozen-rotor interface method was set at the interfaces between rotation and stationary domains.

A grid dependency test was carried out in a range of 1,200,000 - 8,000,000 nodes to determine the optimum number of grids as shown in **Fig. 3**. This figure shows the velocities at the points located between the adjacent fins, which distribute on motor body in circumferential direction. Through the test, about 5,000,000 were determined as the optimal number of grids, which consists of about 300,000, 700,000, and 4,000,000 nodes in the inlet duct, rotating impeller, and low-voltage motor body, respectively.

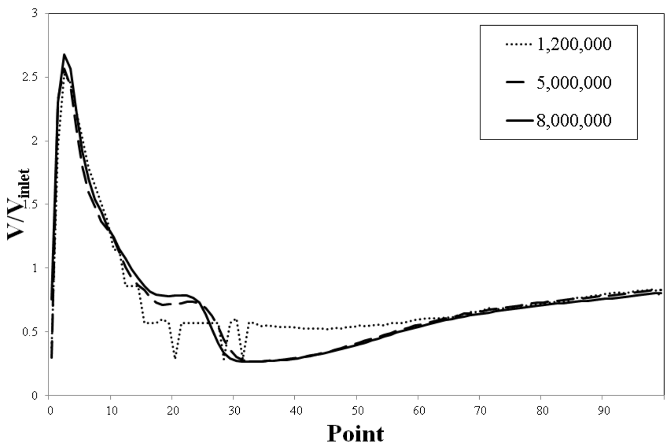



*Figure 3: Results of grid dependency test for flow velocities at the points located between the fins on motor body*

The root mean squared residual value of the momentum and mass equations were set to fall below 10E−06. The physical time-scale was set to 1/ω, where ω is the angular velocity of the blades. The computational time was typically 15 – 18 hours, depending on the geometry considered and convergence rate. The present calculations were performed by Intel Core I7 CPU 874K and a clock speed of 2.94 GHz.

## PARAMETRIC STUDY

In the present work, a parametric study was carried out for the aerodynamic performance of the motor cooling fan, and the parameters related to the geometry of the blade and fan casing. A back plate was installed in the middle of the fan blades. Distance between blade tongue and center (*Pi*), installation degree ($\theta_f$) of the back plate, and number of blades (*N*) of fan impeller shown in **Fig. 4**, were selected as the geometric parameters to be tested.

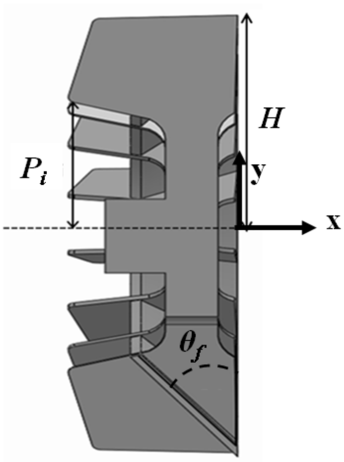



*Figure 4: Definition of geometrical parameters*

## RESULTS AND DISCUSSION

The numerical results based on k-ε turbulence model have been compared with experimental data measured in this work for flow velocities at the points located between the fins on motor body in circumferential direction as shown in **Fig. 5**, where the numerical results show good agreements with the experimental data. **Figure 6** shows the variations of aerodynamic performances of the cooling fan with the geometric parameters. Variations of mass flow rate and torque of the cooling fan with number of blades are shown in **Fig. 6(a)**. Both the mass flow rate and torque of the cooling fan increase with an increase in the number of blades. Thus, the cooling fan with $N = 24$ shows the best aerodynamic performance among the tested numbers of blades. As for the $P_i/H$, the cooling fan having $P_i/H = 0.51$ shows the maximum mass flow rate and minimum torque a shown in **Fig. 6(b)**. And, **Fig. 6(c)** clearly shows that torque decreases rapidly with an increase in the installation angle of back plate. This indicates that aerodynamic performance of cooling fan is highly sensitive to the installation angle of back plate.

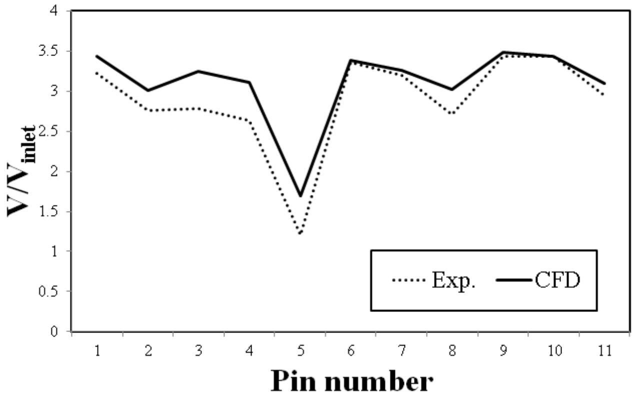
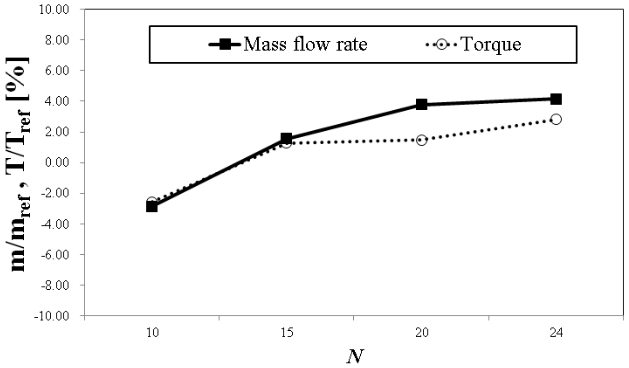
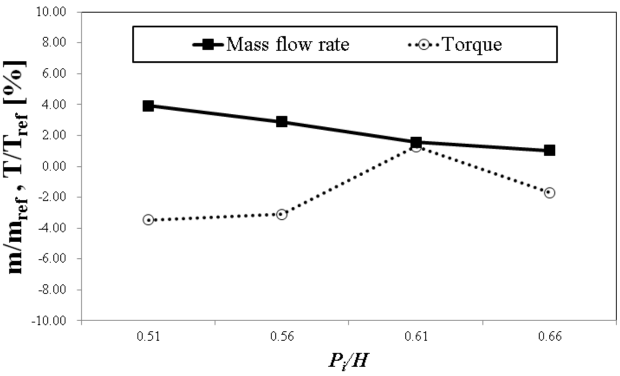


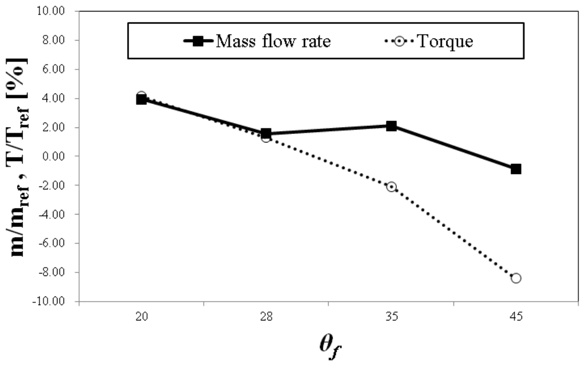

*Figure 5: Validation of numerical results for flow velocities at the points located between the fins on motor body*




(a) $N$




(b) $P_i/H$




(c) $\theta_f$

*Figure 6: Variations of performance functions with geometrical parameters*

The streamlines at 80% span of impeller having different numbers of blades are presented in **Fig. 7.** The large vortex in the blade passages (dashed circle) is observed in case of $N$ = 10. The size of this vortex decreases with an increase in the number of blades.

**Figure 8** shows streamlines at 70% blade span. In case of $P_i/H$ of 0.66, the largest vortex is generated between blade passages. This vortex size decreases with a decrease in $P_i/H$. The velocity contours on the x-y plane of cooling fan having different installation angles of back plate are represented in **Fig. 9**. For $\theta_f$ = 20º, the high velocity region between the casing and blades (dashed ellipse) is widely distributed in comparison with those of the other cases.

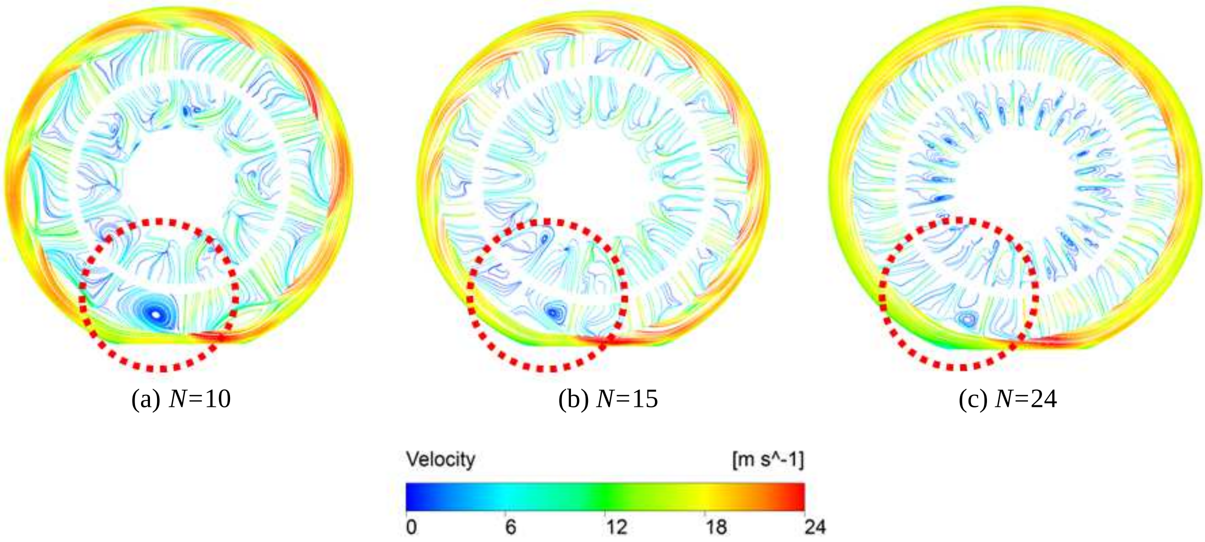



*Figure 7: Streamlines at 80% blade span for different numbers of blades*

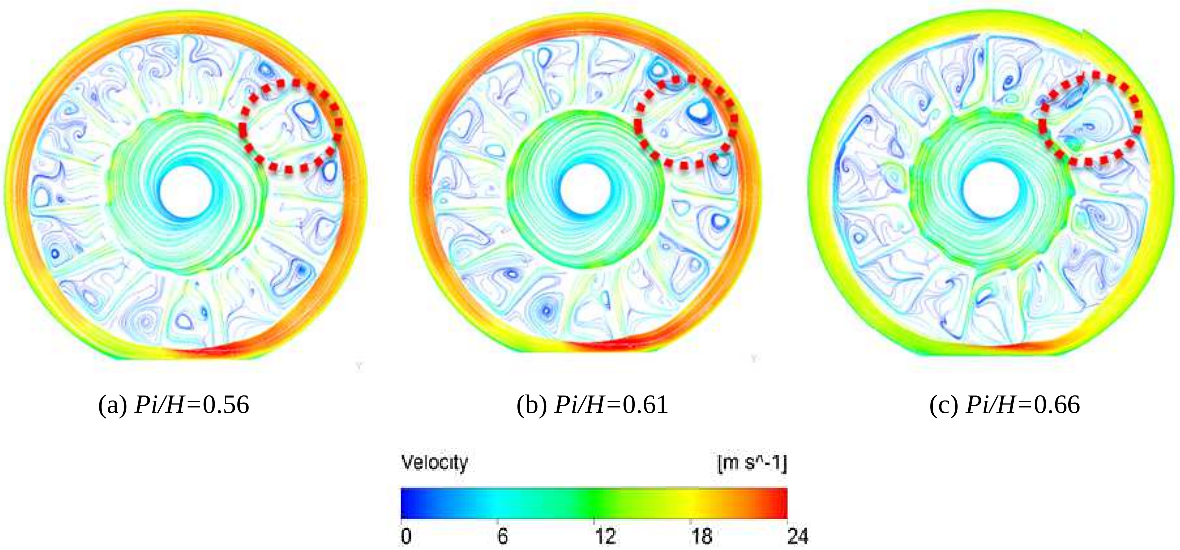
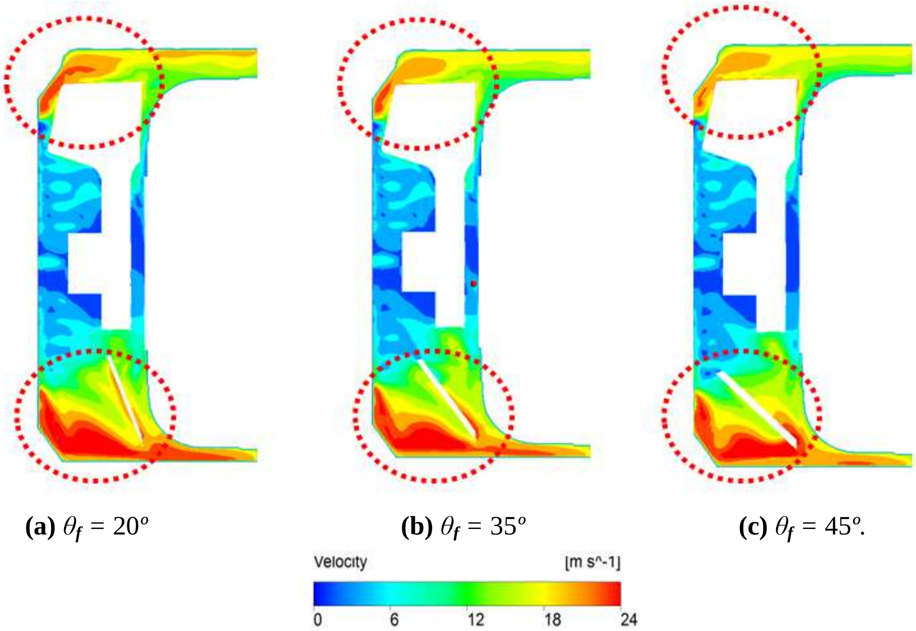



*Figure 8: Streamlines at 70% blade span for different distances between tongue and shaft of blade*




**(a)** $\theta_f = 20^o$ **(b)** $\theta_f = 35^o$ **(c)** $\theta_f = 45^o$.

*Figure 9: Velocity contours on the x-y plane for different installation angles of back plate*

## CONCLUSIONS

A parametric study of a cooling fan in a low-voltage electric motor has been performed using three-dimensional RANS analysis. The present numerical results for the cooling fan showed good agreements with the experimental results. The effects of blade geometry on aerodynamic performance of motor cooling fan were investigated. Tested parameters were related to the geometry of blades, i.e., distance between blade tongue and center of impeller, number of blades, and installation angle of back plate. The mass flow rate of cooling fan increases as the number of blades increases, and also as the distance between blade tongue and center of impeller and installation angle of back plate decrease. And, it was found that torque of motor cooling fan is most sensitive to the installation angle of back plate compared to the other geometrical parameters.

## AKNOWLEDGEMENT

This work was supported by Electrical Engineering Research Department, Hyundai Heavy Industries Co., Ltd. The authors gratefully acknowledge this support.

## BIBLIOGRAPHY

[1] R. Grimes, M. Davies, J. Punch, T. Dalton, and R. Cole – *Modeling Electronic Cooling Axial Fan Flows*. Journal of electronic packaging, Vol. 123, pp. 112-119, **2001**

[2] H. Li – *Cooling of a permanent magnet electric motor with a centrifugal impeller*. International Journal of Heat and Mass Transfer, Vol. 53, pp. 797-810, **2010**

[3] E. Walsh, P. Walsh, R. Grimes, and V. Egan – *Thermal Management of Low Profile Electronic Equipment Using Radial Fans and Heat Sinks*. Journal of Heat Transfer, Vol. 130, pp. 125001-1～8, **2008**

[4] C. C. Chang, Y. F. Kuo, J. C. Wang, and S. L. Chen – *Air cooling for a large-scale motor*. Applied Thermal Engineering, Vol. 30, pp. 1360-1368, **2010**

[5] ANSYS CFX-15.0 Theory Guide of ANSYS CFX 15.0, ANSYS Inc., **2014**