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Design criteria for water cooled systems of induction machines

Marco Satrústegui\textsuperscript{a}, Miguel Martinez-Iturralde\textsuperscript{a}, Juan C Ramos\textsuperscript{a}, Patxi Gonzalez\textsuperscript{b}, Gorka Astarbe\textsuperscript{b}, Ibon Elosegui\textsuperscript{a}

\textsuperscript{a}Ceit and Tecnun (University of Navarra), Paseo Mikeletegi 48, San Sebastian 20009, Spain
\textsuperscript{b}OBEKI, Poligono Apatua Eerreka c/Baratzondo 3, Ibarra 20400, Spain

Abstract

An analytical thermal model of an IC71W Induction Machine (IM) is presented, introducing the most relevant theoretical assumptions and equations. The validation of this model is conducted through experimental measurements. Some criteria for design of the most critical parts of the cooling system are provided using both a model based on Computational Fluid Dynamics (CFD) techniques and the analytical thermal model. First, the design of the water jacket and its main parameters are broadly analysed and some correlations for the design of the cooling ducts are presented. The influence of wafters on this cooling arrangement is also discussed.

Keywords: Induction machine; Water cooled; CFD; Analytical model; Thermal design

Nomenclature

Latin symbols

\begin{align*}
A_{\text{duct}} & : \text{cross sectional area of the water jacket (m}^2) \\
A_{\text{jacket}} & : \text{contact surface between the fluid and the housing (m}^2) \\
c_p & : \text{specific heat of the material (J/kg \cdot K)} \\
D_{\text{ext,s}} & : \text{stator external diameter (m)} \\
D_h & : \text{hydraulic diameter (m)} \\
f & : \text{friction factor obtained with the Colebrook-White equation (non dimensional)} \\
G & : \text{thermal conductance matrix of the thermal circuit (W/K)} \\
h_{\text{ch}} & : \text{height of the cooling duct of the water jacket (m)} \\
h_{\text{water,ch}} & : \text{height of the cooling duct in the water jacket (m)} \\
h_{\text{Fe,water,ch}} & : \text{distance between the cooling ducts and the stator stack (m)} \\
l_{\text{water,jacket}} & : \text{axial length of the water jacket (m)} \\
L & : \text{characteristic length in the direction of growth of the boundary layer (m)} \\
m & : \text{water mass flow rate in the water jacket (kg/s)} \\
P & : \text{power loss source associated to the node (W)} \\
P & : \text{vector containing losses in the nodes of the thermal circuit (W)} \\
P_{\text{Convection}} & : \text{Heat dissipated by natural convection from the housing to the ambient (W)} \\
P_{\text{Loss}} & : \text{Electromagnetic losses of the machine (W)} \\
Pr & : \text{Prandlt number (non dimensional)} \\
Q_{\text{water}} & : \text{heat evacuated by the water (W)} \\
Q_{\text{water}} & : \text{water volumetric flow rate in the water jacket (m}^3/s) \\
\dot{r}_{\text{out}} & : \text{outer radius of the generic cylindrical component (m)} \\
\dot{r}_{\text{in}} & : \text{inner radius of the generic cylindrical component (m)} \\
Re & : \text{Reynolds number (non dimensional)} \\
R_{i,j} & : \text{thermal resistance between nodes i and j of the circuit (K/W)} \\
R_x & : \text{thermal resistance number x (K/W)} \\
T & : \text{vector of temperatures of the thermal circuit (K)} \\
T_{\text{w,out}} & : \text{temperature of water at the outlet of the water jacket (K)} \\
T_{\text{w,in}} & : \text{temperature of water at the inlet of the water jacket (K)} \\
T_x & : \text{temperature number x (K)} \\
V_{\text{erosion}} & : \text{allowable maximum speed in order to avoid erosion in the water jacket (m/s)} \\
V_{\text{water}} & : \text{speed of water inside the water jacket (m/s)} \\
W_{\text{ch}} & : \text{width of the cooling duct of the water jacket (m)} \\
W_{\text{water,ch}} & : \text{width of the cooling duct in the water jacket (m)} \\
W_{\text{water,ch,space}} & : \text{distance between two consecutive cooling ducts (m)}
\end{align*}
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