

Motor-CAD: Through ventilation model.

Dave Staton - Motor Design Ltd.

The article follows on from one featured in the previous edition of the Flux Magazine – Modelling of Convection in Motor-CAD. It describes the through ventilated model implemented in Motor-CAD. Through ventilation is the cooling type where air or any other fluid is forced to flow through the internal structure of the machine. We will concentrate on air cooling in this article. Motor-CAD can however model any gas/fluid.

Model Basics

Typically there are three parallel flow paths through the machine - stator & rotor ducting and the airgap. Examples of the ducting types currently available in Motor-CAD are shown in Fig 1. The machine dimensions are input using the cross-section editors shown in Fig 2.

Motor-CAD allows the user to specify a fixed volume flow rate or input the fan characteristic for the fan/blower being used – this is done using the dedicated editor shown in Fig 3. The intersection of the fan characteristic and the system characteristic is then calculated (also shown in Fig 3) so that the volume flow rate and resulting

velocity in all sections of the machine are known. The velocity information is then used to calculate the local heat transfer coefficients (h , [W/m²/C]) and ultimately the thermal resistances used in the thermal schematic (Fig 4). The heat transfer coefficients are calculated using proven empirical convection heat transfer correlations based on dimensional analysis [1].

Flow Network Analysis

The flow resistances that are used in the calculation are based on flow network analysis [2]. The governing equation that relates pressure drop (P [Pa], flow equivalent of voltage in an electrical system) to volume flow rate (Q [m³/s], equivalent to electrical current) and resistance (R [kg/m⁷]) is:

$$P = R Q^2$$

The formulation is in terms of Q^2 rather than Q due to the turbulent nature of the flow.

Two types of flow resistance exist. Firstly where there is a change in flow condition – such as expansions and contractions in the flow circuit and restrictions due to obstructions in the flow path. Secondly due to



Figure 1: Examples of duct types available in Motor-CAD.



Figure 2: Motor cross-sections editors.

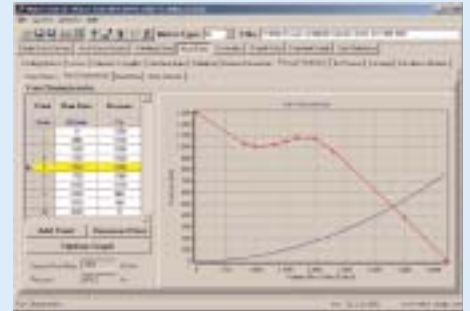


Figure 3: Fan and system resistance characteristics.

fluid friction at the duct wall surface - this is usually negligible compared to the first type of resistance due to the comparatively short flow paths. The flow resistance is calculated for all changes in the flow path using the formula:

$$R = k \rho / (2 A^2)$$

Where k is the dimensionless coefficient of local fluid resistance whose value depends upon the local flow condition (obstruction, expansion, contraction, etc). Formulations have been added to Motor-CAD to calculate the k factors for all changes in flow section within the motor - the most appropriate formulation being assigned automatically to the particular flow path component, i.e. a sudden contraction to when air enters the stator/rotor ducts, a 90 degree bend where the air passes around the end winding, etc. ρ is the air density (kg/m³) and A is the area of flow section that relates to the k factor formulation.

Thermal Resistance Network

Fig 4 shows the thermal resistance and power network that is solved. The resistances and power sources/sinks (drawn as current sources) are color coded to the components given in the radial, axial and winding editors (Fig.2). Convection and radiation resistances are marked with C and R symbols respectively. Interface resistances between components have three colors

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with the central color usually being white to signify air. For each surface within the machine, the internal dissipation to the through ventilation air is shown by the power sinks.

Design Example

An example of the through ventilation model in use will be presented at ICEM 2002 [3]. Motor-CAD was used to model the 1150hp blower cooled induction motor shown in Fig 5. The motor's internal geometry is input using dedicated editors as shown in Fig 2 (for confidentiality reasons dimensional data has been intentionally altered). Fig 3 shows the intersection of the fan (blower) characteristic and system flow resistance characteristic for the motor being considered. The resulting total volume flow rate is 3300CFM. Temperature and power flow predictions within the motor are shown in the schematic diagram shown in Fig 4. Excellent agreement with test was achieved, the measured winding hot spot being 157°C and the calculated value being 159°C.

Conclusions

This article has briefly taken a look at the through ventilation model used in Motor-CAD. As with all calculations in Motor-CAD, the through ventilation flow and heat transfer calculations are performed automatically with the most appropriate formulations being used. This means that the user need does not to be an expert in thermal heat transfer analysis to obtain reliable results.

References

- [1] Incropera, F.P. & DeWitt, D.P.: Introduction to Heat Transfer, Wiley, 1990.
- [2] Idelchik, I.E.: Handbook of Hydraulic Resistance - Coefficients of Local Resistance and of Friction, 1960
- [3] Al'Akayshee, Q. & Staton, D.A.: 1150 hp motor design, electromagnetic and thermal analysis, ICEM 2002, Bruges, Belgium

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Figure 4: Thermal schematic showing steady-state temperatures and power flow.



Figure 5: 1150hp through ventilated induction motor (courtesy of Mawdsleys Ltd, UK).



October 22-24, 2002 at CEDRAT
Thermal Analysis of Electric Motors

3D thermal analysis.

Christophe Guérin, Marc Vilcot - CEDRAT.

Starting this year, the new FLUX3D version 3.30 includes a transient thermal module. To demonstrate the new transient thermal module, a FLUX3D application has been developed from the FLUX2D tutorial on the steady state and transient heating of a thyristor-radiator assembly.

Thermal transfers by convection and radiation are described on the surfaces of the device. Thermal properties can depend on the temperature (straight line, exponential curve, user subroutine).

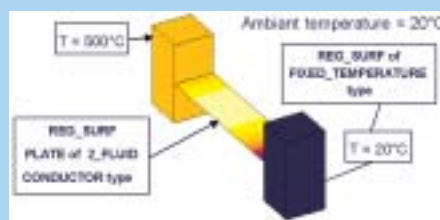
In addition, the thermal applications (steady state thermal and transient thermal), like the magnetic applications, allow the use of

thin volume regions to describe domains with small thickness without meshing these regions. This feature is illustrated in the example opposite.

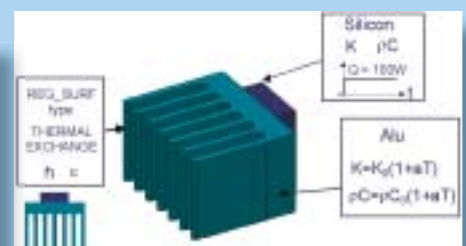
Obviously, the thermal modules of FLUX perform any thermal computation whose sources (dissipated power density) come from an electromagnetic problem.



Extraction of the power density (thermal source) to the thermal module.



Heat conduction in a thin plate with different thermal transfer coefficients on its two faces.



Computation of the 3D transient temperature distribution.

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