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Research Paper

Thermal analysis of a canned switched reluctance drive with a novel network

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HIGHLIGHTS

- A novel thermal network of high accuracy is studied.
- Detailed modeling approach is described.
- Heat transfer of a canned switched reluctance motor is studied.
- Thermal characteristics are given via measurement.

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ABSTRACT

This paper presents thermal characteristics of a novel canned Switched Reluctance Machine (SRM) as a hydraulic pump drive. Due to considerable ohmic loss from the can shield structure, thermal analysis is essential. A novel lumped parameter network model featured by using compensation elements is proposed. As a result, calculation accuracy is improved by removing traditional systematic error. The modeling process is described in detail, including thermal resistances and compensation elements. Accuracy of the model is validated by both finite element method (FE) and measurement.

1. Introduction

A canned electrical machine drive integrated with a hydraulic pump is capable of working in liquid being pumped. In particular, the approach of mechanical seal is a characteristic feature [1]. Compared with conventional machines, a can, a pipe-like or sleeve hollow cylinder is inserted in airgap as partition. Consequently, the liquid may get into airgap, but is isolated out of armature windings. Therefore, the machine is canned, making the pumping system work with high reliability and easy maintenance.

The use of can shield makes it thoroughly different. The can shield is metallic alloy to satisfy mechanical reliability and manufacturing requirement. The alloy is non-magnetic with higher electrical resistivity but not laminated. As a result, the eddy current on the can shield, called "can loss", is seen considerable, causing characteristic heat transfer and temperature rise that will be investigated in this paper.

The predominantly used canned machines are induction machines [2–4] preferring constant speed operation. With increasing demand of efficiency improvement, more attention has been paid on fluid regulation by a variable speed pump drive with lower loss compared to throttling. Therefore, the use of alternative machines attracts many research interests and the canned permanent magnet machine is reported [5]. However, permanent magnets are not fully utilized due to enlarged airgap length. Canned switched reluctance machine (SRM) as a hydraulic pump drive is deemed as a prospective candidate. SRMs offer higher starting torque as well as flexible speed variations. The high reliability, robustness, simple structure and low cost have attracted researches [6–8].

A 20 kW 3-phase 12/8 canned SRM under study is shown in Fig. 1. The only and most characteristic feature is the enlarged airgap in which can shields are fixed. There are duals cans, namely stator can (outer can) and rotor can (inner can). The stator can is to keep coils out of the liquid being pumped while the rotor can

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Nomenclature

Thermal resistance R_{th} Between (&)

$R_{th\_fr\_am}$	frame & ambient
$R_{th\_SY\_fr}$	stator yoke & frame
$R_{th\_SY\_ST}$	stator yoke & stator teeth
$R_{th\_wi\_ST}$	windings & stator teeth
$R_{th\_wi\_SY}$	windings & stator yoke
$R_{th\_wi\_EW}$	windings & end windings
$R_{th\_ST\_OC}$	stator teeth & outer can
$R_{th\_OC\_IC}$	outer can & inner can
$R_{th\_IC\_RT}$	inner can & rotor teeth
$R_{th\_RT\_RY}$	rotor teeth & rotor yoke
$R_{th\_RY\_sh}$	rotor yoke & shaft
$R_{th\_wi\_SA}$	windings & slot air
$R_{th\_OC\_SA}$	outer can & slot air

Compensation element t Toward (→)

$t_{ST\to OC}$	stator teeth → outer Can
$t_{OC\to ST}$	outer can → stator teeth
$t_{OC\to AG}$	outer can → air gap
$t_{IC\to AG}$	inner can → air gap
$t_{IC\to RT}$	inner can → rotor teeth
$t_{RT\to IC}$	rotor teeth → inner can
$t_{RT\to RY}$	rotor teeth → rotor yoke
$t_{RY\to RT}$	rotor yoke → rotor teeth
$t_{RY\to sh}$	rotor yoke → shaft
$t_{EW\to wi}$	end windings → windings
$t_{wi\to EW}$	windings → end windings
$t_{wi\to ST}$	windings → stator teeth
$t_{ST\to wi}$	stator teeth → windings
$t_{SY\to ST}$	stator yoke → stator teeth
$t_{ST\to SY}$	stator teeth → stator yoke
$t_{SY\to wi}$	stator yoke → windings
$t_{wi\to SY}$	windings → stator yoke
$t_{SY\to fr}$	stator yoke → frame

Heat source P Component

P_{SY}	stator yoke
P_{ST}	stator teeth
P_{wi}	windings
P_{EW}	end windings
P_{OC}	outer can
P_{IC}	inner can
P_{RT}	rotor teeth
P_{RY}	rotor yoke

Thermal conductivity k_c Component

k_{c_aly}	alloy (machine body)
k_{c_cop}	copper
k_{c_wi}	windings (with coating)
k_{c_can}	can
k_{c_air}	air
k_{c_liq}	liquid (stationary water)
$k_{c\_eff\_liq}$	moving liquid

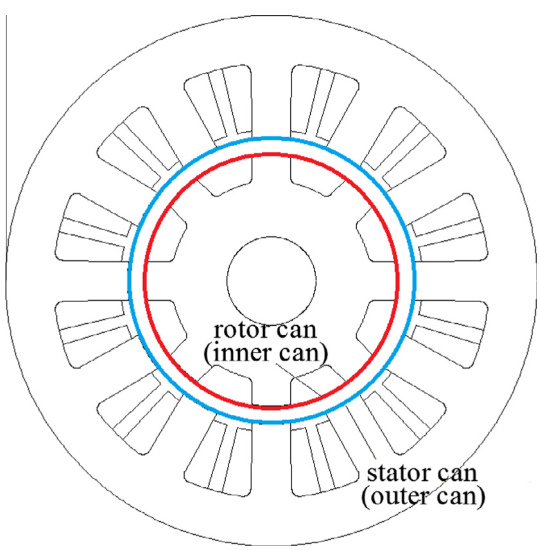

Fig. 1. The canned switched reluctance machine under study, featured by having dual cans in airgap.

is to reduce friction by rotor saliency. Cooling liquid is able to go between cans to directly take away heat from each can.

Thermal analysis is an important aspect for electrical machines design [9–13]. As to canned SRMs, this is particularly necessary, as the can loss is considerably higher [6–8] than counterparts such as copper or iron loss. Identification of temperature rise on the cans plays the central role, including the overall rise and local thermal sensitive regions.

A fast and accurate mathematic heat transfer model is essential and one classic is the lumped parameter network. Derived from machine geometry, heat sources, material and cooling, this model takes all components and heat transfer mechanisms [14–22]. However, the heat flow is considered constant within the volume being estimated, whereas in fact it alters [23–25], causing systematic mistake. In the past, such mistake is eliminated by curve fitting or heat transfer coefficients.

In this paper, an accuracy improved lumped parameter thermal network is developed by adding compensation elements. The model is validated from component level to whole machine by both FE and measurement. Besides, thermally sensitive regions of the machine are identified, which is essential for high performance of canned SRMs.

2. The thermal analysis principle

The necessity of using compensation elements as a measure of accuracy improvement is illustrated with related previous work [26,27]. Temperature distribution, lumped network model and comparative simulations of a block component as example are shown in Fig. 2. Assuming that heat source is evenly distributed in the block and identical lateral 4 faces of the block is thermally isolated. Accordingly the network is created while improvement is made via adding additional compensation elements t_{comp}, which is obtained by

$$t_{comp1} = (P_{Loss}/4)\cdot(R_{TH,1}/2) \tag{1}$$

$$t_{comp2} = (P_{Loss}/4)\cdot(R_{TH,2}/2) \tag{2}$$

$$t_{comp} = t_{comp1} = t_{comp2} \tag{3}$$

All calculations are shown in Fig. 2. The traditional network overestimates temperature rise while the improved network with t_{comp} and FE fit each other. Such a mistake of the traditional network is previously eliminated by curving fitting procedure. For complicated systems of more than one component, t_{comp} can be still introduced.