Applied Thermal Engineering 31 (2011) 978–983

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Field winding fault diagnosis in DC motors during manufacturing using thermal monitoring

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ARTICLE INFO

Article history:
Received 16 July 2010
Accepted 21 November 2010
Available online 1 December 2010

Keywords:
DC motors
Fault diagnosis
Electric machines
Infrared imaging

ABSTRACT

Quality assessment during DC motor manufacturing should involve quality controls designed to detect various fault conditions associated with the components included in the machine.

Some defects, however, can be produced by the automatic manufacturing process during the assembly of the individual components. Inter-turn short-circuits, turn to earth short-circuits and open winding, among other fault conditions, can result from the field poles manufacturing and insertion inside the stator. The main problem with these kinds of faults is that though the motor is likely to be operational, there is a high probability of motor breakdown in the near future.

In this paper, the above fault conditions are analyzed and a thermal model and an infrared monitoring test method for manufacturing quality control is proposed.

1. Introduction

The manufacturing of small DC motors is a complex process involving the compilation of numerous parts. One of the most critical operations is the assembly of the poles inside the stator frame. Among others, the placement of the poles can be the origin of faults such as inter-turn short-circuits, winding to earth faults and open windings.

Grubic et al. [1] surveyed the state of the art concerning testing and monitoring methods (mainly those relating to turn insulation problems) for stator insulation of low-voltage induction machines. Our research deals with DC motors rather than induction machines, however, there are some basic ideas that are machine independent.

Syggeridou et al. [2,3] established that the detection of fault conditions is more efficient in cases where a combination of different diagnostic methods, such as mechanical, chemical, thermal, etc., is employed.

Penman et al. [4] presented a paper that describes a technique based on axial leakage flux sensing. The methodology makes it possible to not only detect the occurrence of a turn fault but also to locate its position in the winding. Furthermore, the method can be used while the motor is running.

Asaii et al. [5] presented a simplified thermal model that can be used for predicting the winding temperature even in transient conditions.

In spite of the fact that thermal analysis of electric machines has received less attention than electromagnetic analysis, there has been increasing activity in this discipline during the last several years [6–8].

The sections that follow introduce the basic structure of the pole field winding and, at the same time, an equivalent electric and thermal circuit is proposed. This equivalent circuit is used as a starting point in order to propose a test system and a methodology. While some references related with this topic can be found, almost all of them are related to running machines [9–14].

As this study is devoted to manufacturing problems, the rotor is not considered: it is assumed that the rotor has not yet been put inside the stator frame during the fault detection process.

This method is intended for quality control testing during manufacturing. If the defects are detected before the rotor is mounted inside the stator, manufacturing costs can be reduced.

2. Field structure

The field of a conventional DC motor has a structure similar to the one shown in Fig. 1. The analyzed machine has six poles but the analysis can be extended to machines with *n*-poles. From an electrical point of view and considering a steady-state model, the lumped equivalent circuit of the six-pole machine under study is introduced in Fig. 2. The equivalent circuit is defined as

$$U_{ad} = R_{p_i} I_{p_i} + (R_{c_+} + R_{c_-}) \sum_{i=1}^{6} I_{p_i} \tag{1}$$

where: U_{ad} Field voltage in *V*. I_{p_i} Current at the *i*th-winding in *A*. R_{c_+} Equivalent resistance of the winding to general connection point

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doi:10.1016/j.applthermaleng.2010.11.023

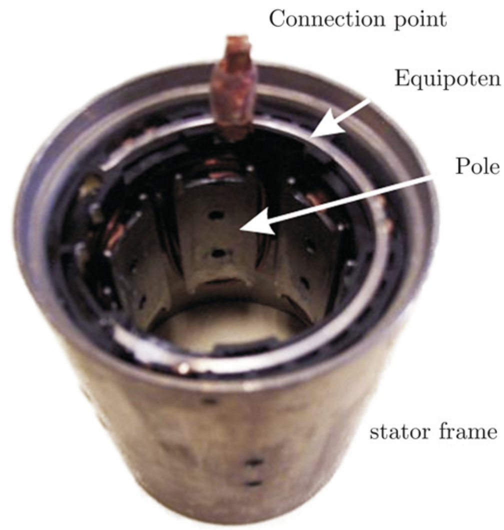

Fig. 1. Six-pole DC machine under analysis.

(supply voltage terminal) in Ω; R_{c_-} Equivalent resistance of the winding to general return connection point (supply reference terminal) in Ω; R_{p_i} Equivalent resistance of the i winding in Ω.

Considering the voltage at poles U_{bc}, the current I_{p_i} at the i-winding is

$$I_{p_i} = \frac{U_{bc}}{R_{p_i}} \tag{2}$$

The field current I_s is

$$I_s = \sum_{i=1}^{6} I_{p_i} \tag{3}$$

A failure in one or more windings can be modeled as a variableR_{p_i}. Two types of failures have been considered:

i Open winding. A pole with an open winding can be represented as an infinite resistance. That is $R_{p_i} \to \infty$.

ii. Winding inter-turn short-circuit. A winding with inter-turn short-circuit can be represented with a lower resistance than an undamaged pole. A short-circuit parameter $\alpha \in [0, 1]$ is introduced, so the i-pole winding resistance will be αR_{p_i}.

Considering a current I_{p_i} flowing through the winding of the i-pole whose resistivity is $\rho[\Omega mm^2/mm]$, cross-section area is A_p $[mm^2]$, length l_p $[mm]$ and current-density $J_{p_i} = I_{p_i}/A_p[A/mm^2]$, the heat production rate W_{p_i} per unit volume is

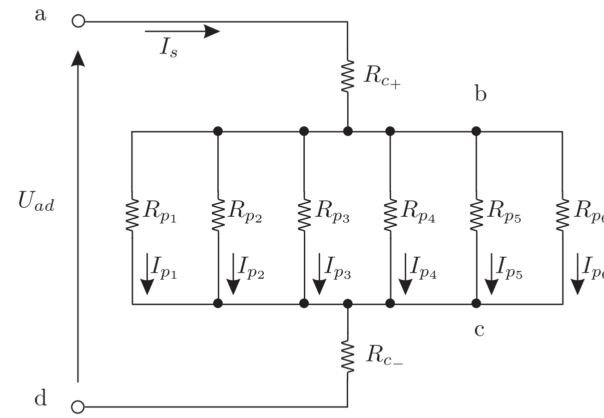

Fig. 2. Simplified electric model of the 6 pole DC machine analyzed.

$$W_{p_i} = \frac{\rho \frac{l_p}{A_p} I_{p_i}^2}{A_p l_p} = \frac{\rho I_{p_i}^2}{A_p^2} = J_{p_i}^2 \rho \tag{4}$$

and the power P_{Cu_i} dissipated in the i-pole conductor is

$$P_{Cu_i} = W_{p_i} A_p l_p = J_{p_i}^2 \rho A_p l_p \tag{5}$$

A winding without failures exhibits a length l_p. A DC Power Source with current control is used so the current I_s can be set to the desired value. If the field includes and open winding, the faulty pole current density will be zero. On the opposite, if the field includes a winding with inter-turn short-circuit then its current density will be greater than the winding without faults. From a practical point of view the measurement of the winding resistance with an ohmmeter cannot be considered. This is due to the fact that the value that has to be measured is small compared with the tolerance introduced by the terminals and the manufacturing process.

3. Thermal model

From a general point of view, the heat inside the motor is removed by various phenomena: i) air convection, ii) conduction and iii) radiation. Air convection is important in running motors, and therefore irrelevant in this setup facility as there is no forced air flow inside the structure. As for radiation, it is insignificant compared with conduction, but cannot be neglected if the surface is painted or lacquered black.

The temperature distribution within the machine is a diffusion problem. It is extremely difficult to obtain accurate temperature values because some parameters such as the thermal contact resistance between conductors and poles are empirical and have to be determined for each case.

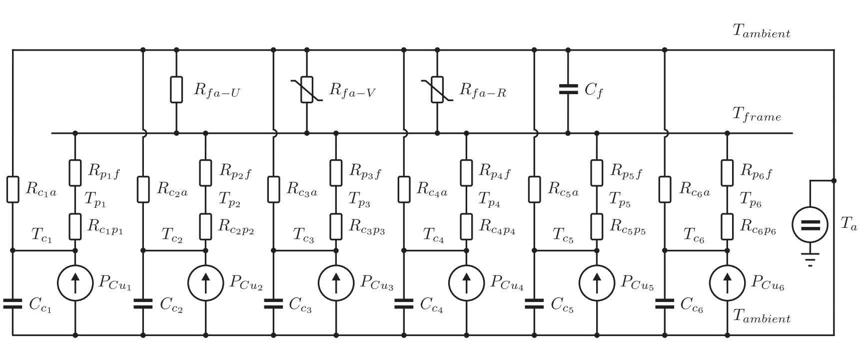

Fig. 3. Detailed thermal equivalent circuit for the 6-pole motor without rotor.