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Rotor shielding influence on the detection of induction machine flux position

T.M. Wolbank [a,*], J.L. Machl [a], H. Hauser [b]

[a] *Department of Electrical Drives, Vienna University of Technology, Gusshausstrasse 25-29/372, A-1040 Vienna, Austria*

[b] *Department of Sensor and Actuator Systems, Vienna University of Technology, Gusshausstrasse 25-29/366, A-1040 Vienna, Austria*

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Abstract

In induction machines, the knowledge of more than the fundamental wave values of voltage and current can be used for higher efficiency, reduction of costs and size, and on-line condition monitoring. By evaluating the transient electrical behavior, the machine acts like an embedded sensor itself. While the transient electrical behavior is heavily influenced by the depth of penetration of the flux into the rotor, it is strongly dependable on the shielding effects taking place in the machine. For this contribution the specially attached shielding to the rotor and its influence on the detected behavior is discussed. It is shown, that a huge influence on the transient behavior can be found, while the change of fundamental behavior is negligible.

Keywords: Shaft-sensorless control; Transient electromagnetic behavior; Lamination material anisotropy; Induction machines

1. Introduction

The exploitation of the transient behavior of an ac-machine is nowadays used for achieving a lot of additional information on the machines operating state when compared with using only the fundamental wave parameters and quantities. Since this additional information can lead to some profitable benefits it is of high importance. These benefits can be for example omitting a mechanical position sensor and thus reducing costs and size of a drive as well as increasing its reliability. Another field of application of this information is on-line condition monitoring of ac-machines. In this particular contribution we only deal with the behavior of induction machines. The additional information is extracted by indirect flux detection by on-line reactance measurement (known as the INFORM-method, proposed in Ref. [1]).

While the transient electrical behavior is influenced by the fundamental wave quantities, it is also strongly influenced by design parameters [2], the lamination material anisotropy [3], as well as the shielding effects that take place in the machine itself. This paper is focused on the last topic.

For inspection reasons, the shielding was attached artificially by fixing thin copper onto the rotor surface of the considered induction machine.

2. INFORM method principles

The method applied in this investigation is usually called INFORM in the literature (indirect flux detection by on-line reactance measurement). Here only the basic principles are described. The method is explained in detail in Ref. [1].

The main idea is the detection of asymmetries in the transient reactances of machines by evaluating the current step response due to voltage pulses. Therefore a voltage pulse caused by the switching of the inverter is applied to the terminals of the machine and the resulting current change is measured, using the sensors available in standard industrial inverters.

To minimize the disturbance on the stator current during the injection sequence, the duration of the pulses is limited to

* Corresponding author. Tel.: +43 1 58801 37226; fax: +43 1 58801 37298.
E-mail address: thomas.wolbank@tuwien.ac.at (T.M. Wolbank).

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some 10 μs. Alternatively they may also be integrated into the current control scheme.

The current change is influenced by different parameters. First of all the dc link voltage, which is kept constant during an evaluation period by the capacitors, can influence the step response. Other influences are caused by the voltage induced by the movement of the rotor flux, or the voltage drop of the stator resistance. By proper selection of the switching states applied, the last two influences can be eliminated. In the following these influences are assumed to be eliminated leaving only the effect of asymmetries in the transient reactances. As the current change is measured in all three phases, these three parts can be combined to a resulting current change space phasor. If the machine was exactly symmetrical this current change phasor due to a transient excitation in the direction of one phase axis should point exactly in the direction of this axis. However, resulting from the saliencies a modulation is detectable. The tip of the current change space phasor evaluated for a pulse excitation in a single phase describes a circle. The center of this circle is determined by the symmetrical mean value of the transient machine reactance and is thus a measure of the mean level of saturation.

For a transient excitation in each phase a separate circle is obtained showing an offset in the direction of the corresponding phase. This offset can be either eliminated feed forward or by combining the results of all three phase directions. The resulting phasor is often denoted as INFORM phasor and contains the spatial information of all saliencies that influence the transient reactance, as such as saturation, slotting, and anisotropies.

Fig. 1 gives an overview of the INFORM testing sequence (rectangular voltage pulse sequence), the response from the induction machine (triangular trace) as well as the extracted locus of the transient saliency signal (lower). In the resulting control signal locus of Fig. 1, all saliencies are contained, but not all are obviously visible. The clearly visible ones are caused by the fundamental wave saturation and the slotting. The saturation dependent component is the most prominent. It causes the locus to rotate twice around the center of the complex plane (thus it is fixed to twice the flux angle). The order number of two is due to the direction independent effect of the fundamental wave saturation. The less prominent component is the slotting anisotropy. Since the rotor- as well as the stator winding is placed in discrete slots, this causes an asymmetry in the reluctance distribution. This causes 24 “minor circles” (only 12 can be seen clearly, because of the two rotations caused by saturation). Obviously the rotor must have 22 slots per pole pair. This causes 24 circles to appear since it is superposed onto the two major circles. Considered as spatial harmonics, these effects appear as second order harmonic (saturation) and as −22nd order harmonic (slotting). It has to be stressed, that the saturation due to its high order of nonlinearity, caused by the magnetising curve, causes some additional harmonics (−4th, 4th, 6th, . . .), however, since they are much less distinct, they are not used as control signals and are filtered by means of digital filtering or artificial neural networks.

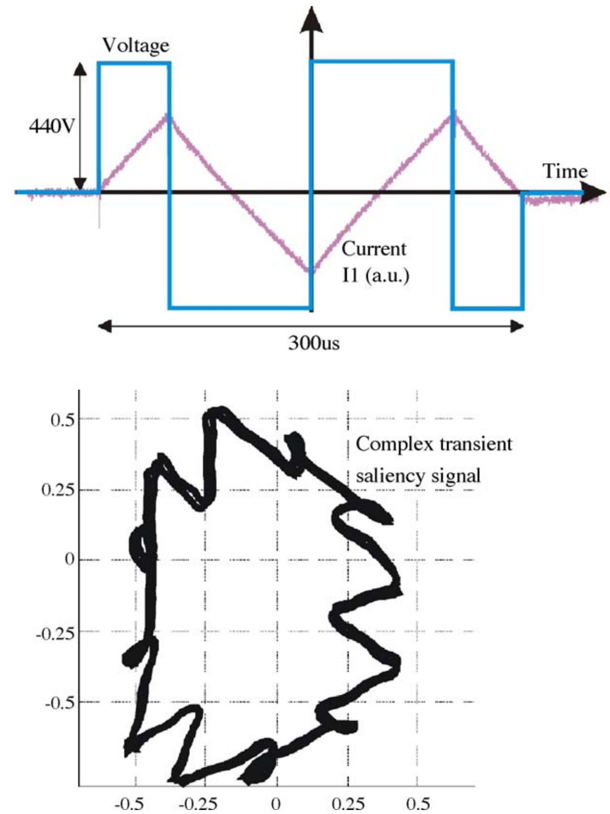

Fig. 1. (Upper) Injection signal and corresponding current response of the INFORM method; (lower) locus of the extracted saliency signal of a standard induction machine (complex plane; a.u.).

3. Lamination material anisotropy in the transient electrical behavior

The effect of the lamination material anisotropy was first investigated in Ref. [2]. While this anisotropy is not really visible in the fundamental wave behavior of the machine it has been mostly neglected, except for the transient response of the machine, it has a greater influence than expected at first. To show this, special measurements have been performed.

For these special measurements the flux has been fixed to the rotor (idealized no-load condition) and a measurement cycle over one electrical revolution was performed. This was repeated with the flux pointing in all directions of the rotor. Despite the fact that the “saturation component” should always point in the same direction as the double flux angle (negative real axis of Fig. 2), it is modulated by the flux angle in the rotor reference frame. This has to be an effect that is related to the rotor. The assumption that this is the lamination material anisotropy was tested in the following way. In a special manufactured rotor, all sheets have been aligned with respect to the rolling direction and the measurements described above have been performed again (left part Fig. 2). All the lamina has been stacked in a way, such that the rolling direction has been twisted by one rotor tooth every sheet. The smallest quantity of this twist was, due to the rotor cage, one tooth pitch. Once again the same measurements have been evaluated and compared to the first one (right part Fig. 2). The “pulsation” caused by the rotor-fixed anisotropy has