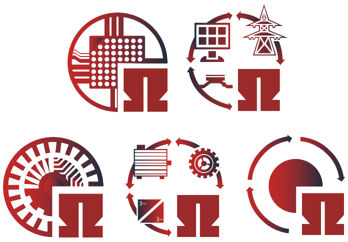
ELSYS Note



Induction motor removed rotor cage test

Core loss and excess rotor copper loss due to flux pulsations in the air-gap are difficult to measure, and are present in every squirrel cage induction motor. These losses depend mainly on the geometric topology. This ELSYS note will explain an unsual method or rather not so typical measurement to isolate the rotor copper loss from the total no load loss. Special attention is given to the calculated and measured iron loss components and how the difference could be accounted for in the design phase.

Excluded rotor cage

This ELSYS Note discusses the challenges in induction motor loss calculation and the importance of understanding material properties and manufacturing processes. The focus of this note is to explain the problem and emphasize a rather untypical and practical measurement setup in which the induction motor rotor cage winding is excluded. The initial considerations arise from a bachelor's thesis [1].

Temperature rise test

For a re-design of an induction motor it was required to reduce the number of stator slots from 60 to 36. For double layer stator windings this means less stator coils and has the potential to reduce the manufacturing steps and save cost. In this particular case the rotor design was unchanged.
The test results from the temperature rise test are given in Tab. 1. Especially the temperature rise from the rotor is eye-catching, i.e. $\Delta_{\text{Rotor}} = 260\,\text{K}$. This is far beyond the measured value from the standard design of $\Delta_{\text{Rotor}} = 114\,\text{K}$. As a result the initial guess of the high total loss of $P_{\text{tl}} = 19.9\,\text{kW}$ during the test was an increase in the iron loss due to flux pulsations in the teeth of both the stator and rotor.

Table 1 Temperature rise test

Q_s	60	36
f/Hz	50	50
P_{in}/kW	215	190
U_{LL}/V	580	522
I_s/A	250	255
$P_{\text{Cu,s}}$/kW	7.0	5.8
P_{tl}/kW	14.2	19.9
η/%	93.4	89.5
ΔT_{Stator}/K	114	161
ΔT_{Rotor}/K	114	260

Component Separation

Motor losses can be separated into friction and windage loss, winding copper loss, and iron core loss. It is difficult to separate these losses during measurements. For a sinusoidal measurement the total loss will be the sum of the friction, copper loss and iron loss. Thus P_{tl} can be expressed as follows:

$$P_{\text{tl}} = P_{\text{friction}} + (P_{\text{Cu,s}} + P_{\text{Cu,r}}) + (P_{\text{Fe,s}} + P_{\text{Fe,r}}) \quad (1)$$

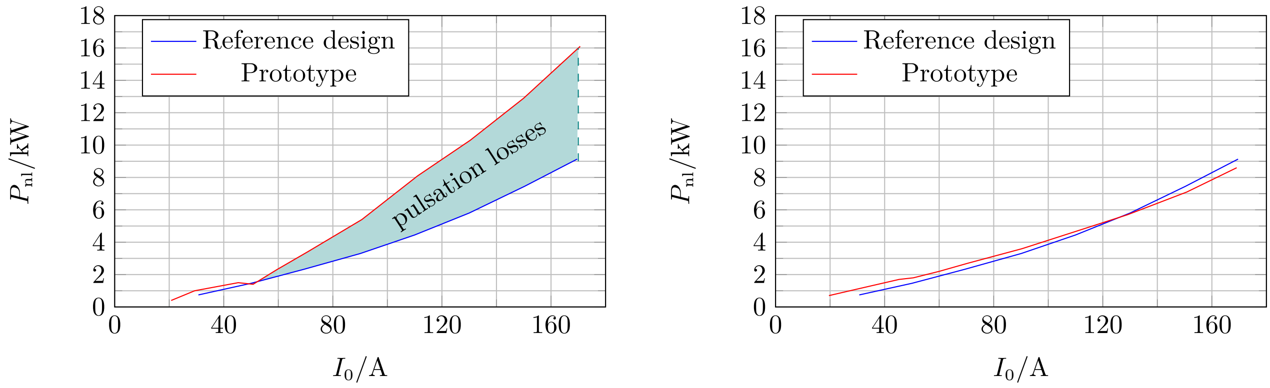
Especially magnetic field discontinuities in the air-gap can lead to confusion when interpreting results. Under ideal conditions the rotor losses $P_{\text{Cu,r}}$ and $P_{\text{Fe,r}}$ in (1) should be neglible under no-load operations. Typically $P_{\text{Cu,s}}$ and $P_{\text{Fe,s}}$ should explain the reason for the measured excess loss.

Experienced based

Designing an induction motor often requires complex calculations, with iron loss calculation being particularly challenging. It relies on correction factors based on years of experience. Tab. 2 reports the percentage increase in loss at each manufacturing stage and the cumulative percentage increase relative to the Epstein loss, denoted as Δ_{stage} and Δ_{cum} respectively. Importantly, the manufacturing factor, as reported in [2], aligns with that presented in Tab. 2. This alignment underscores the significance of incorporating established manufacturing practices into the intricate process of induction motor design.

Table 2 Increase in loss [3]

Stage	Δ_{stage}	Δ_{cum}
Epstein	-	-
Cutting	15 %	15 %
Stacking	25 %	44 %
Winding	5 %	51 %
Housing	35 %	104 %



(a) Including the rotor cage

(b) Removed rotor cage

Fig. 1 Comparison of the measured input power for $T_{\mathrm{load}} = 0\,\mathrm{Nm}$ at 50 Hz

No Load Losses

The no-load test provides insights into exciting current and no-load losses. Stator copper losses are appreciable due to larger exciting current, while rotor copper losses are assumed to be negligible. No-load measurements at 50 Hz reveal the dependency of the no-load losses ($P_{\mathrm{nl}} = P_{\mathrm{tl}}$) as a function of magnetizing current as shwon in Fig. 1(a). In general it is standard praxis to classify the "unknown losses" as iron losses. Typically, as a result, the correction for the iron losses wil vary withing a small range.

Transient FEA

Even considering an iron loss correction factor of 2 as presented in [2], the increase in the total losses could not be explained. Detailed FEA showed that the actual cause of the increase is the eddy-currents in the rotor bars due to flux pulsations as shown in Fig. 2, i.e. excluding the short-circuit ring. Thus, $P_{\mathrm{Cu,r}}$ is not neglible as typically expected and the main reason for the pulsation losses.

Fig. 2 Bar eddy-current

Test without Cage

From FEA, two essential tests were conducted: one with only rotor copper bars (no short-circuit ring) and one without the rotor cage. The test with only rotor bars validated FEA, yielding results akin to Fig.1(a). Removing the cage replicated losses of the reference motor (Fig.1(b)), confirming excess rotor copper loss. Comparison of total losses without the cage (Fig. 3 without the cage $P_{\mathrm{Cu,r}} = 0\,\mathrm{W}$) affirmed calculated rotor copper loss accuracy.

Fig. 3 Induction motor removed cage test

Conclusion

The exclusion of the rotor cage in induction motor testing exposed the cause of unexpected temperature rise – flux pulsations impacting rotor copper losses. This study underscores the importance of considering flux pulsations' effects on both iron and copper losses. Combining analytical and FEA calculations enhances our understanding of induction motor behavior, providing crucial insights to improve efficiency and design methodologies.

References

[1] Michael Gitter. "Untersuchungen der Pulsationsverluste eines Asynchronmotors". Diplomarbeit. Technische Hochschule Nürnberg Georg Simon Ohm, 2004.

[2] Johannes Germishuizen and Scott Stanton. "No load loss and component separation for induction machines". *18th International Conference on Electrical Machines*. 2008, pp. 1–5. DOI: 10.1109/ICELMACH.2008.4800074.

[3] *Measurement technologies for soft and hard magnetic materials*. Brockhaus Measurement. 2021.