ELSYS Note

Lesson from Esson

During the initial dimensioning phase of a machine design, the Esson coefficient is a valuable instrument to relate the mechanical and electrical quantities. A 260 kW traction motor prototype is used to discuss the use of the coefficient in the early design phase. From the current versus speed results for different reluctance torque components, the relationship with the Esson coefficient is pointed out. The Esson coefficient is a good step towards a well-thought-out initial dimensioning and probably the simplest way to relate the mechanical and electrical quantities.

Initial dimensioning

The Esson coefficient C is a simple relationship between the mechanical and electrical quantities and a useful tool when drafting the initial geometrical dimensions. Originating in 1890 [1] and featured in German literature as early as 1908 [2], the Esson coefficient has evolved as a cornerstone in the initial dimensioning of machines. The primary electrical quantities which define the machine performance are the fundamental flux density in the air-gap $\hat{B}_\delta$ and the current loading A_1. On the other hand the bore diameter D, axial length l and rated speed n are the primary mechanical quantities. C in $\mathrm{W\,s\,m^{-3}}$ is expressed as follows:

$$C = \frac{P}{D^2\, l\, n} \geq \frac{\pi^2}{\sqrt{2}}\, k_\mathrm{w}\, \eta\, \cos\varphi\, \hat{B}_\delta\, A_1$$

where k_w represents the winding factor and $\cos\varphi$ the power factor.

Significance of the Coefficient

In Tab. 1, we present guideline values for air-cooled induction machines proposed by W. Nürnberg in 1952. These values serve as invaluable benchmarks for the initial dimensioning process. To enhance comprehension, we express the Esson coefficient C in terms of torque density τ, utilizing conversion constants outlined in the triangle diagram in Fig. 1. This approach not only facilitates a more intuitive understanding but also emphasizes the practical significance of the Esson coefficient in laying the groundwork for effective machine design.

Table 1 Values for air-cooled machines

Sym./Unit	Size S	Size L
k_w	0.96	0.92
$\cos\varphi$	0.70	0.90
η	0.70	0.90
$\hat{B}_\delta/\mathrm{T}$	0.78	0.90
$A_1/\mathrm{kA\,m^{-1}}$	20	55
$C/\mathrm{kW\,min\,m^{-3}}$	0.85	4.29
$\sigma/\mathrm{N\,cm^{-2}}$	0.52	2.61
$\tau/\mathrm{kNm\,m^{-3}}$	10.38	52.17

The attainable Esson coefficient is intricately linked to the operating **speed** and **cooling** methods of an application. While this note primarily focuses on losses affecting cooling, it is essential to recognize that only coefficients within the same speed range are comparable.

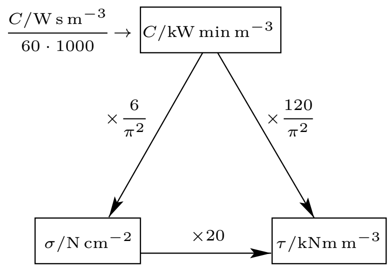

Fig. 1 Conversion Triangle

IPM Traction Motor Design

In a 260 kW traction motor design [3, 4], systematic geometrical variations of the reluctance torque component were explored to balance current in the constant torque region with losses in the constant power region.

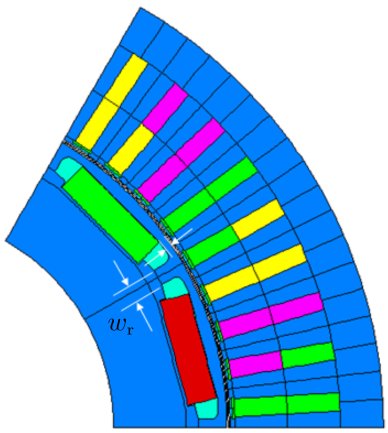

Fig. 2 IMP Motor Design [3]

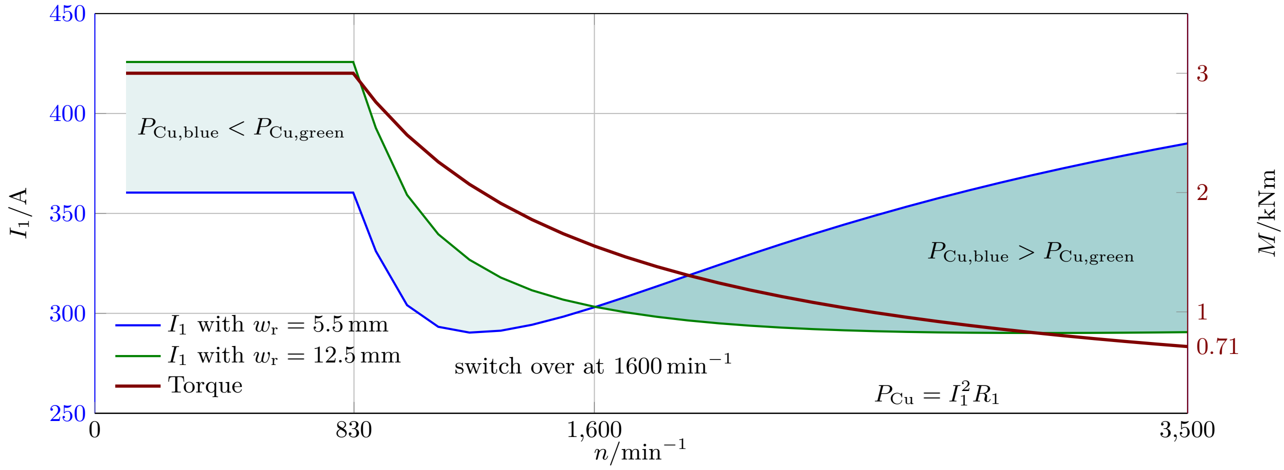

Fig. 3 $M(n)$ characterisitc for a 260 kW traction motor

The rotor, designed with a typical interior magnet topology as depicted in Fig. 2, incorporates radial joints connecting the retaining ring and rotor yoke, chosen to withstand mechanical stress at maximum speed. Losses in the constant power range affecting cooling were assessed by varying w_r between 5.5 mm and 12.5 mm.

Torque Characteristic

Fig. 3 illustrates the torque-speed characteristics of two motor designs. The blue curve represents the design with $w_r = 5.5$ mm, while the green curve represents the design with $w_r = 12.5$ mm. Notably, there's a clear switch over of the current at approximately 1600 rpm. In the constant torque region, the blue design exhibits lower current, increasing rapidly when the voltage limit is reached. In contrast, the green design has higher current in the constant torque region due to an added reluctance torque component. After the switch over at around 1600 min^{-1}, the green design with $w_r = 12.5$ mm experiences lower copper loss. This observation underscores the impact of adding reluctance torque on losses and, consequently, cooling. Results for the key indicatos are presented in Tab. 2.

Table 2 Design results [4]

Parameter	green	blue
I_1/A at $n_{\max}$	291	385
w_r/mm	12.5	5.5
w_m/mm	50	60
T_{pm}/Nm	324	396
T_{reluc}/Nm	387	317

With rotor width w_r as the parameter, stator current I_1 varies from 291 A to 385 A, impacting total copper loss. This parameter-specific analysis offers insights into thermal loading origins, aiding tailored designs for specific application specifications.

Conclusion

In conclusion, the Esson coefficient serves as a vital link between mechanical and electrical considerations during initial dimensioning. Examining a 260 kW traction motor design reveals intricate tradeoffs. Critical insights from torque-speed characteristics emphasize the need for a holistic design approach, recognizing the Esson coefficient's guidance in initial dimensions and the essential consideration of losses for optimal efficiency and performance.

References

[1] W.B. Esson. "Some points in dynamo and motor design". *Journal of the Institution of Electrical Engineers* 1 (1890), pp. 118–168.

[2] Karl Pichelmayer. *Dynamobau*. Band 5 von Handbuch der Elektrotechnik / Handbuch der Elektrotechnik. Verlag S. Hirzel, 1908.

[3] Jonas Bruckschlögl. "Analyse von verschiedenen Rotorgeometrien einer permanenterregten Synchronmaschine für Traktionsanwendungen mit einem weiten Konstantleistungsbereich". Diplomarbeit. Technische Hochschule Nürnberg Georg Simon Ohm, 2019.

[4] J. Bruckschlögl, J. Germishuizen, and A. Kremser. "Design optimisation of IPM machines considering the constant power range". *19th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF)*. 2019. DOI: https://doi.org/10.1109/ISEF45929.2019.9097003.