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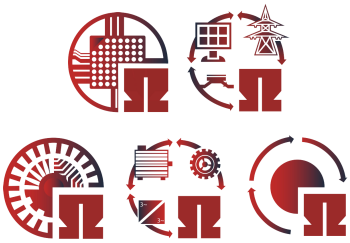
ELSYS Note



From Requirements to Machine Geometry

Preliminary machine design is a process of progressively reducing the design space. Starting from the torque–speed requirement or available installation volume, each design decision narrows the range of feasible machine configurations. The selection of the winding concept, conductor technology, and slot geometry determines the principal machine dimensions and provides a practical foundation for subsequent electromagnetic, thermal, and mechanical optimisation.

Where to start

A first look at an electric-motor catalogue can be overwhelming for newcomers. The many machine types, frame sizes, winding configurations, cooling concepts, and manufacturing technologies may suggest an almost unlimited number of possible designs. In practice, the design space becomes considerably smaller once a few fundamental decisions have been made.

Machine design normally starts from the required torque–speed envelope. The Esson coefficient provides a first estimate of the main dimensions. Alternatively, the available installation volume may already be prescribed. The resulting bore volume can then be used to estimate the achievable torque.

Every design decision reduces the design space. Once the bore volume is known, only a limited range of slot numbers, winding layouts, and conductor technologies remains practical.

The stator-slot number is closely related to the bore diameter, winding arrangement, and manufacturing process. An early decision is therefore whether an overlapping or non-overlapping winding should be used. Induction machines normally employ overlapping distributed windings, whereas synchronous machines may use either arrangement.

Winding concept

The winding concept must not be selected from electromagnetic considerations alone. The stator provides the principal heat-transfer path for the copper losses. Non-overlapping windings employ tooth coils, which offer short end windings but may provide less effective thermal contact with the stator core. Distributed overlapping windings generally require more slots, but spread the copper over a larger stator circumference and may therefore provide a more favourable thermal path.

The next decision concerns the conductor and winding technology. Random-wound round-wire windings are comparatively simple and cost-effective. Form-wound coils provide a defined conductor arrangement, but are generally more difficult to manufacture. Hairpin windings combine a defined geometry with a high degree of automation, although the available layouts and interconnections may restrict the achievable number of series turns.

These decisions lead to a first estimate of the bore diameter and active stack length. The selected winding also determines the winding overhang, as shown in Fig. 1. Although it does not contribute to torque production, it affects the total machine length, copper mass, resistance, leakage inductance, and thermal behaviour.

Once the principal dimensions and winding concept have been selected, the remaining design effort shifts from choosing a machine concept to optimising its performance. The overall design procedure is summarised in Fig. 2.

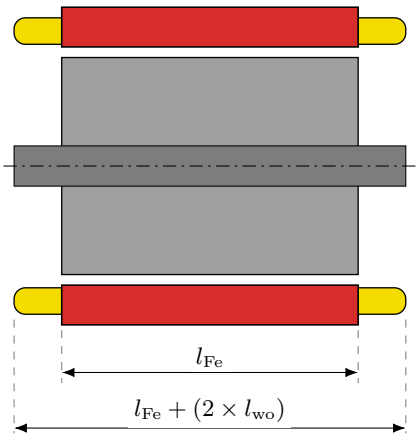


Fig. 1: Main axial dimensions

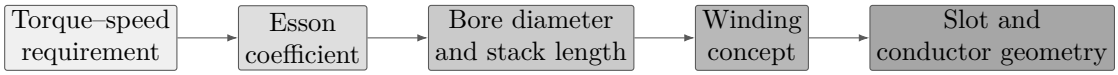


Fig. 2: Successive reduction of the machine-design space

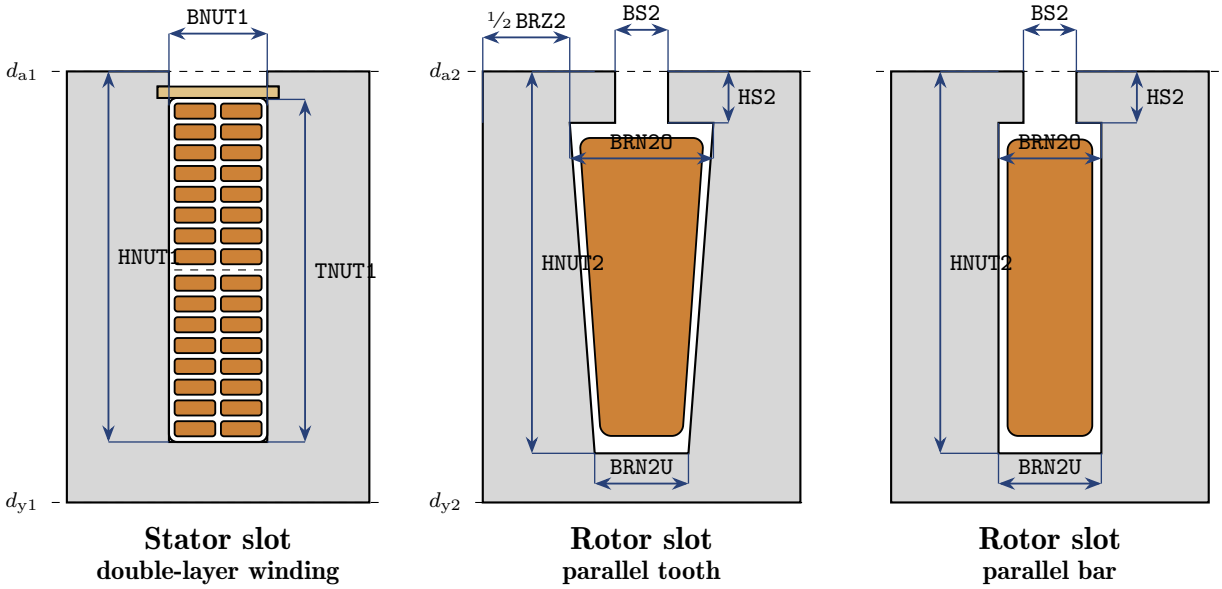


Fig. 3: Slot geometries

Reference machine

The induction machine provides a useful reference for a first design study. Its construction is well documented, and analytical procedures, design examples, and established parameter ranges are widely available. Even when it is not the final choice, it provides a useful benchmark for understanding the influence of the principal design variables.

Form-wound double-layer windings are especially suitable for illustrating these principles. Their regular conductor arrangement makes the number of conductors and series turns per slot immediately visible. They also provide a convenient basis for discussing conductor subdivision, skin effect, and proximity-effect losses.

A detailed step-by-step introduction to induction-machine design is provided in [1]. The book also introduces the use of calculation sheets, which should be established as early as possible during the design process. For more detailed design algorithms and computational procedures, the work presented in [2] is particularly valuable.

The present note therefore focuses on the induction machine. The basic stator- and rotor-slot geometries considered here are shown in Fig. 3. These geometries are well documented and can be investigated using both analytical equations and FEA models. Some of the dimensions and notation used in the figure are based on the analytical machine-design program developed at the **Leibniz University Hannover** [3].

Preliminary design is not about determining every detail. Its purpose is to reduce the design space to a small number of feasible candidates defined by bore diameter, stack length, winding concept, and slot geometry.

References

[1] J.R. Hendershot and T.J.E. Miller. *Design studies in electric machines*. Motor Design Books, 2022. ISBN: 9780984068746.

[2] A. Boglietti, A. Cavagnino, and M. Lazzari. "Computational Algorithms for Induction Motor Equivalent Circuit Parameter Determination – Part I: Resistances and Leakage Reactances". *IEEE Transactions on Industrial Electronics* 58.9 (2011), pp. 3723–3733. DOI: 10.1109/TIE.2010.2084974.

[3] *Rechenmaschinenprogramm ASYN 6.7.1*. Institut für Leistungselektronik und Antriebssysteme. IAL Programmlandschaft. 2025.