# ANALYSIS AND DETERMINATION OF SYMMETRICAL TOOTH COIL WINDINGS

**D. Hülsmann**

## 1 INTRODUCTION

On the subject of symmetrical three-phase windings various analytical descriptions and classifications exist. In case of conventional distributed windings (i.e. with overlapping end-windings) the most common quantity to characterize the winding is the number of slots per pole and phase $q$. According to the value of $q$ (either integer or fractional) two types can be distinguished, namely integer-slot and fractional-slot windings. In recent years windings with so-called tooth coils – formally known as non-overlapping end-windings and mostly indicated as concentrated windings – have become very popular. The main benefits of these topologies are a shortened axial length of the motor and a more cost-effective manufacturing process, due to the fact that each coil is wound around a single stator tooth. Furthermore, single- and double-layer windings have to be distinguished, i.e. one and two coil sides per slot respectively. It should be pointed out that tooth coil windings are mainly used in permanent magnet machines. However, in terms of $q$ these kind of windings are often specified as fractional-slot windings. In various publications (e.g. [1-2]), the misleading impression is often created that this type of winding is subject to a classification of its own, i.e. contradictory with the classical theory. The usual classifications / systematizations found in the literature refers to the number of magnets against the number of slots only (e.g. 2/3, 4/3 or 10/12) and are not reduced to real elementary machines, as the smallest functional unit. The authors in [3] pointed out that two extra factors are necessary to describe one elementary machine with different arrangements of the coils.

The investigations in [7] refer to a systematic of stator windings by W. Kauders (V. Klima) [3-4] established already in the 1930s and recently mentioned in [1]. The author in [3] derives 9 quantities to characterize a symmetrical winding. Furthermore, he presents an equation for a general winding factor calculation with no use of $q$ (a brief introduction is presented in [7]). Applied to the subject of tooth coil windings, this theory implies it as a special case of a generalized superior scheme. It turns out that under consistent application at least 5 quantities are mandatory to identify one elementary machine with tooth coil technology. Besides that, new elementary machines occur that consists of two different zones, i.e. different number of coil-groups per zone (see Fig. 1 d)). These windings – or elementary machines, based on one fundamental wave – have varying properties concerning their harmonic content and in the arrangement of coils.

# 2 EXAMPLE OF A NOVEL ELEMENTARY MACHINE

To get an impression of the possibilities this theory provides, a concrete example is presented in Fig. 1: The primary focus here is on the different distribution of zones around the machine periphery (here in a developed view). The subject is a stator with 18 slots in single-layer winding technology. Fig. 1 a) and b) show the two principle arrangements to build an elementary machine on the 8th ordinal number (16 magnets) in form of a reduced coil-group scheme, a further developed variant of Tingley´s scheme [6]. It should be emphasized that the variant in a) and c) respectively could be already characterized by the quadruple in [3]. Concerning the fundamental wave, the overall winding factors (neglecting the slot opening) of both variants are 0.8312 (variant a)) and 0.9452 (variant b)).

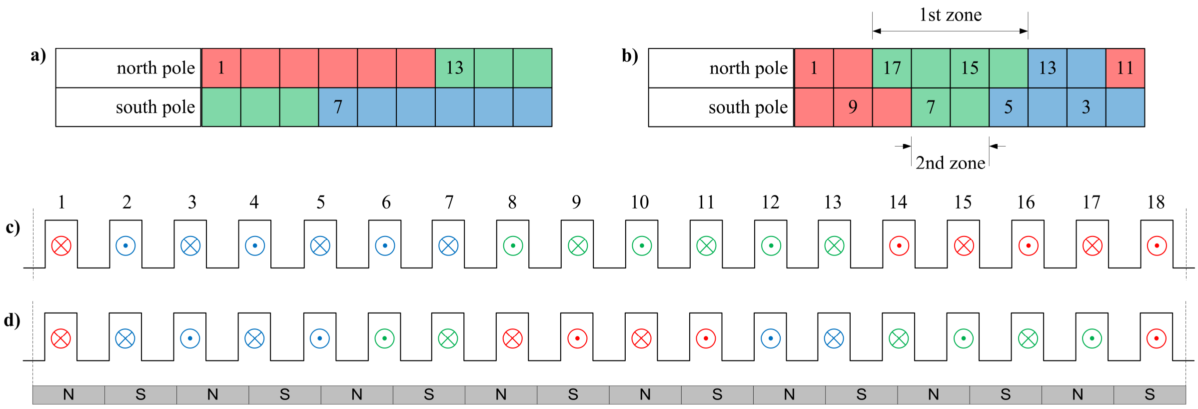


Fig. 1: Reduced coil-group schemes of an 18 slot single-layer machine with 16 rotor poles in variation of

a) just one zone and

b) two different zones,

c) arrangement of coils according to a),

d) arrangement of coils according to b),

colors are assigned to different phases/dots and crosses indicate the direction of winding.

# 3 SUMMARY AND PERSPECTIVE

The suggested systematic in [7] provides a valuable content in the design process of non-overlapping symmetrical three-phase windings, which turn out to represent just a special case of a generalized superior scheme. The determination of the winding factors and the number of turns in each phase allows to specify one elementary machine completely. Concerning all independent quantities and their combinations among each other, it is possible to find suitable elementary machines for single- and double-layer windings. A list of all generated machines, with their winding factors and identifiers, are presented in [7]. The obtained large variety of concepts may be useful to select a favorable elementary machine type to meet the requirements of different applications.

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