Tooth coils with Litz wire: Advantages for E-Drives

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Why and Where Using Tooth Coils

“DW” = distributed winding

“CW” = concentrated winding

Windings options

1-layer DW
1-layer CW
2-layer DW
2-layer CW
Higher Fill Factor with Tooth Coils

Approximate slot fill factors for low-voltage and high-voltage machines with rectangular profiled wire
# Fill Factor related to the Type of Winding Wire

<table>
<thead>
<tr>
<th>Copper Filling Factor</th>
<th>Random wound with enamelled round wire</th>
<th>Litz Wire rectangular</th>
<th>Enamelled rectangular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~ 40 %</td>
<td>~ 65 %</td>
<td>~ 85%</td>
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[Images of winding types and fill factors]
## Problems of Producing Tooth Coils

<table>
<thead>
<tr>
<th>in High Voltage Machines</th>
<th>in Low Voltage Motors</th>
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<tbody>
<tr>
<td>» very narrow coil, very difficult to apply the main wall insulation</td>
<td>» very narrow bending of the wire, tight end winding</td>
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Additional Electrical Losses in Windings due to Eddy currents and Proximity Effect

- Parameter influencing losses:
  - Winding layout: slot opening / in relation to air gap
  - Profile of the wire: height for slot cross field, width for radial field
  - Higher frequencies (as in high speed motors) leading to the circulating currents
Special Wire Solution with Litz Wires

Litz wires are stranded single conductors which are used as high flexible wires or for higher frequencies applications.

High frequency or high flexible applications
›› Single conductor insulated with enamel or Special Surface Treated (SST)

›› HF-Litz wire can be profiled (with a rectangular shape) to achieve higher copper filling factors

›› HF-Litz wire can be covered with tapes (Polyester PET or PEN, Aramide paper Nomex®, PET/Mica Samicafilm®, Polyimide tape Kapton®)
Easier Production with Litz Wires

Example from a medium / high voltage coil
Lower Losses with Litz Wires

Comparison based on:
- same winding area
- slot filling with rectangular wire compared to flat Litz wire

Higher DC winding losses with Litz wire due to smaller fill factor

Lower AC-losses with Litz wire
Design advantage with Litz Wires

The use of Litz wires opens new possibilities for the winding layout in the slots to achieve higher efficiency:

- Impact of cross and radial fields (Bq, Br) would be much less
- Insertion of rectangular Litz wires in half closed slots can be considered
- Reduction of circulating currents due to twisting
- Cross section/Thickness of the profiled wire can be increased
- Filling of the slot with 1 single Litz wire with the same shape
- Optimal slot filling with the Litz wires improves the thermal dissipation compared to random wound
Summary

Advantage of Tooth Coil technology

- Much higher fill factor compared to distributed winding with hair pin or diamond coils
- Coils are easier to produce, manufacturing costs can be reduced

Advantage of Litz wires

- Higher flexibility allowing tight winding and bending of the wire
- Lower electrical losses at higher frequencies (also for distributed windings)
- Enables new slot winding layouts and coil winding technologies for improved efficiencies