# Coil Winding Simulations of Electrical Machines

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## 1 Coil Windings of Electrical Machines

The winding of coils on stator teeth is a central process in the manufacture of electrical machines. The quality of the windings and the associated copper fill factor are important factors for the efficiency of electrical motors. While the copper winding process was manual labor some years ago, this process has meanwhile been completely automated and has been taken over by machines and robots. What is still left for manual labor is the setup of the machines for series production. This can be quite time consuming and costly. To support this setup process, fully understand it in all its details and speed it up, BROSE has used LS-DYNA to develop simulation models for the setup of new coil windings.

*Fig.1: Windung Maschine*

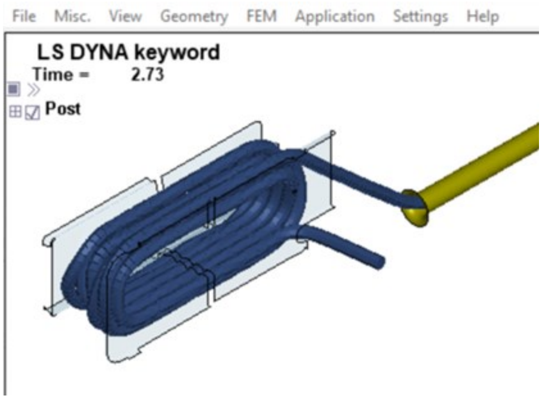


*Fig.2: Windung Simulation [2]*

## 2 Solids vs Beam Elements

The project started out with Solid elements for modelling the copper wire. The main advantage being that all the behavior of the copper wire, like for example thinning under tension, can be modelled in detail. The cost of such detail is calculation time, which can easily take multiple days on 96 cores for a simple winding. Therefore, the use of beam elements has been investigated. While they can't deliver all the details of a solid element model, they proved to be accurate enough to closely mimic the winding pattern generated on a winding machine. At the same time calculation time was reduced significantly.

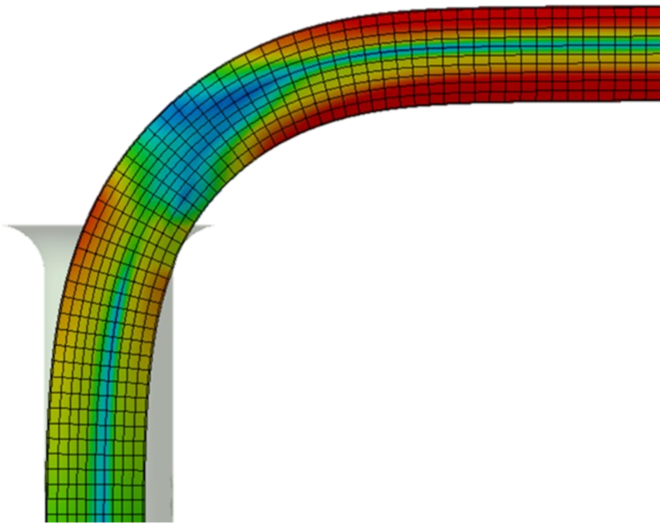

*Fig.3: Solid Mesh [1]*

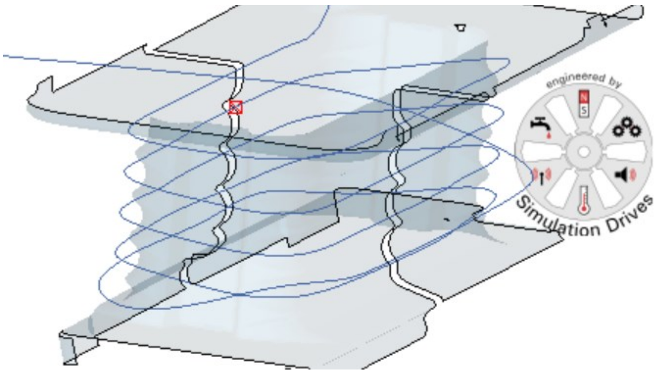


*Fig.4: Beams*

## 3 Reverse Engineering as a Proof of Concept

For validation of our simulation models, the following procedure was chosen. If the recorded movements of a winding machine were used as input for our simulation models, the simulation result should be the same as on the machine. Two machines were chosen for this exercise: A winding machine in the sample shop and a series production machine. While the movement data from the sample shop machine could be recorded on a laptop via a USB connection, there existed no such possibility for the series production machine. The movements of this machine were therefore measured optically with equipment from GOM. Once the machine data was recorded it was fed into the simulation model. The output of the simulation is the deformed shape of the copper wire after the winding process. This result set was then used to generate a 3D CAD geometry, which could be directly compared to 3D scans of the physical windings. The simulation results compared ok with the scans but were not considered close enough.

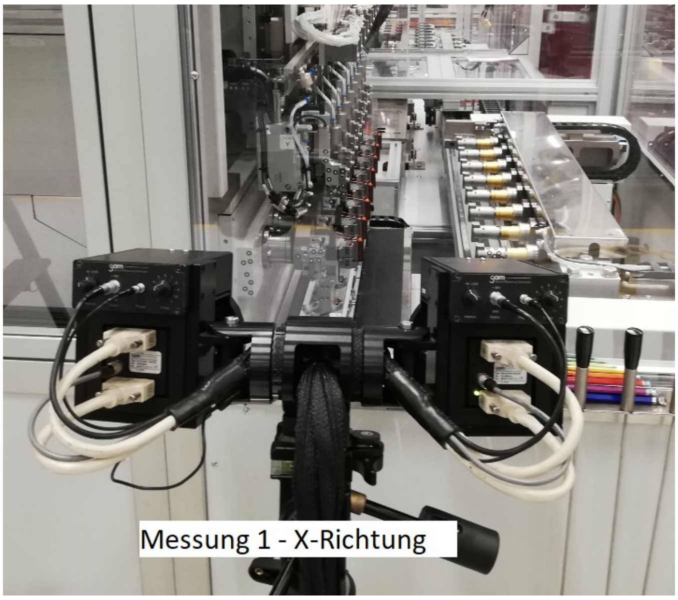


*Fig.5: Optical Measurements*

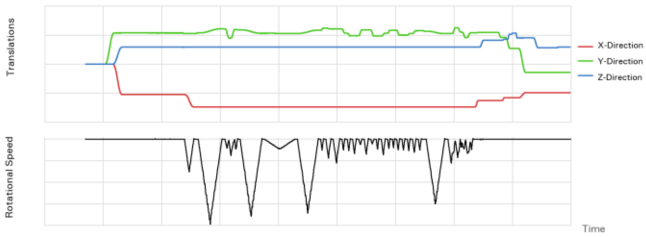


*Fig.6: Machine Movement Charts*

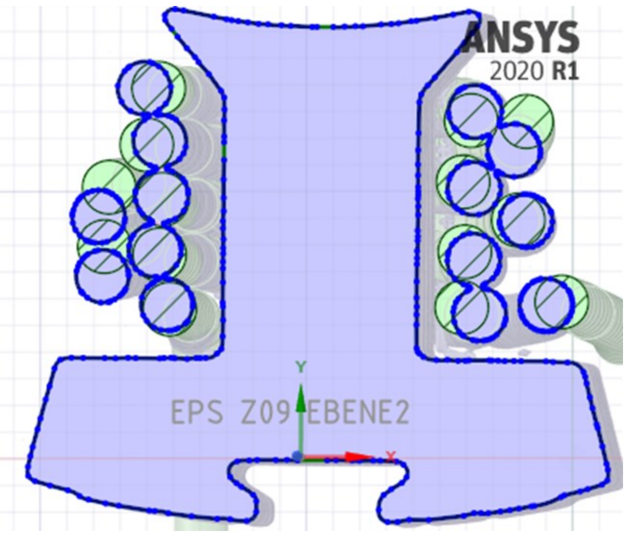


*Fig.7: Scan (blue) overlayed with simulation results (green)*

## 4 Additional Parameters of Influence?

Winding machines have wire brakes, which should ideally ensure that the wire is always under constant tension during winding, which has a direct influence on the winding quality. However, measurement of the wire tensile force on the sample shop winding machine showed strong fluctuations in the wire tension during the winding process. According to advice from experts, the simulation models had previously assumed a constant wire tensile force and needed to be corrected and recalculated according to the new measurements. A renewed comparison of simulations and sample windings finally showed very good agreement throughout. Thus, a validated simulation model for our coil winding processes was achieved.

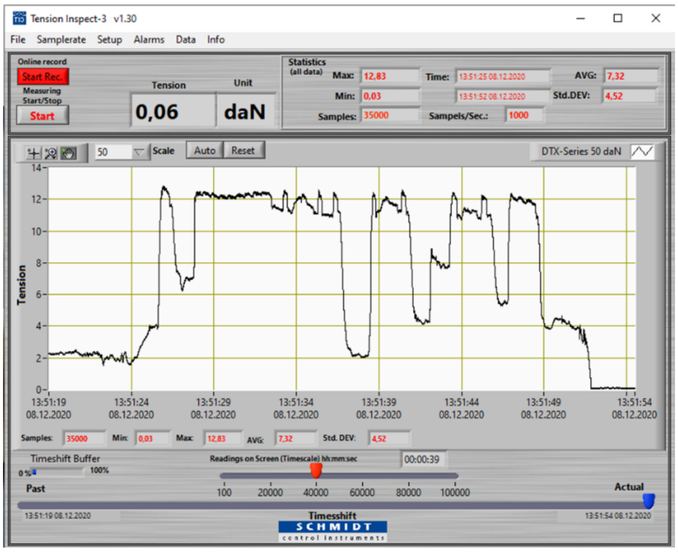

*Fig.8: Wire tensile force.*

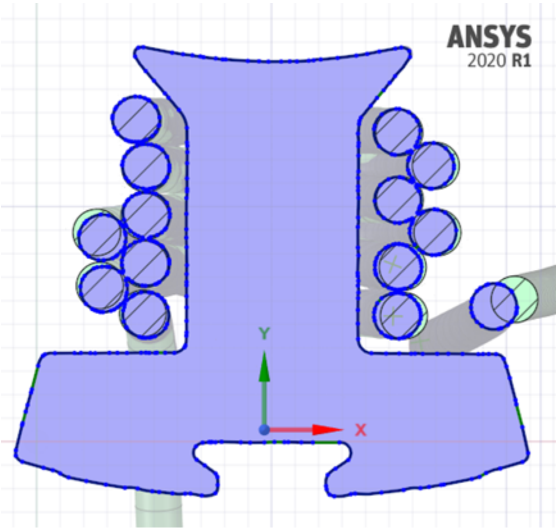


*Fig.9: Scan (blue) overlayed with simulation results (green)*

## 5 Outlook

The validation process was used to prove the accuracy of our simulations. The support for setting up a machine for a new winding pattern works the other way around. The simulation tries to produce a given winding scheme by iteratively mimicking machine movements. This iterative process will obviously benefit from restart capabilities, which greatly reduce simulation time. Once the machine movements are established by the simulation model, they could ideally be fed directly into the machine. The current simulation models are assuming a constant wire tension force. Although this already produces useful results, we already have seen, that the assumption of a constant wire tension force is not quite realistic. We are therefore currently investigating ways to incorporate a wire tension system model into our simulation models.

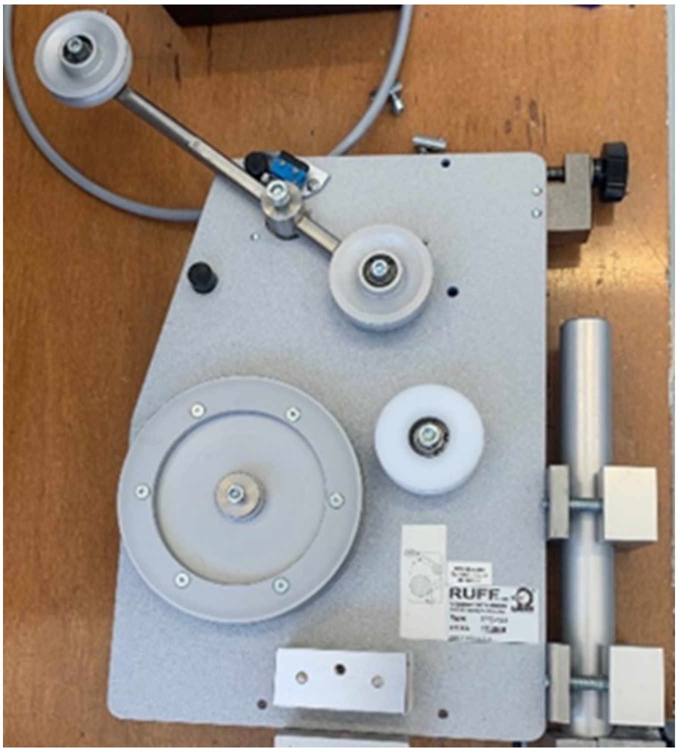

*Fig.10: Wire Tension System*

## 6 Summary

A coil winding simulation model was briefly described. The validation of the simulation model showed good matching with test data after corrections to the wire tension model. The implementation of a wire tension system model into the simulation model is currently under investigation.

## 7 Literature & References

[1] Bähr, M.: "Entwicklung eines Berechnungsverfahrens für die Simulation des Nadelwickelns von Motorspulen mit Automaten", Masterthesis, 2016