# Issues of Material Modeling in Electromechanical Simulations

Takashi Yamada[1], Katsuyuki Narita[1], Hiroyuki Sano[1]
([1]JMAG division, JSOL Corp.)

Many electrical devices are re-designed today in the electrification. Since the electrification is mainly for energy saving or the global warming countermeasures, high energy efficiency is primary requirement of the re-design. A typical example is electric motors of electric vehicles which have to have high energy efficiency as well as high power density with which the conventional internal combustion engines must be able to be replaced.

On the other hand, the further improvement is challenging since such electric machines have long history of over 100 years and countless efforts have been already made in the history. In order to make a breakthrough, advanced simulation technologies such as finite element analysis (FEA) has been introduced and recognized as an indispensable tool in the machine developments. Major advantages of FEA are, firstly, virtual prototyping where any design ideas can be concretely implemented and evaluated and, secondly, detail phenomena in a machine are visualized and investigated. Those advantages give us deep insights in a complex system and substantial improvements which are difficult with conventional design approaches consisting of empirical equations and real prototyping.

However, to enjoy the advantages, the simulation has to have enough accuracy. Since main error source of today’s FEA is material data, accuracy of the material modeling determines performance of the simulation. Hereafter, we focus on losses of lamination steel which is used for core of the electric machines and its property largely affects the performance of the machines. More importantly, the property of the lamination steel is complex and difficult to be modeled so that we have many remaining issues there.

The losses of the lamination steel consist of hysteresis loss, eddy current loss and excess loss. The hysteresis loss is a loss defined by loops of static BH characteristic, i.g. it is frequency independent. The eddy current loss is caused by the classical eddy current circulating in a cross section which is perpendicular to main linkage flux direction. The excess loss is defined as a difference between total losses and summation of the hysteresis loss and eddy current loss.

Most common modeling approaches for loss evaluation today employ an empirical formula such as Steinmetz’s equation in which coefficients and parameters are determined with measurements. The measurements are usually done with a pure sinusoidal waveform of magnetic flux density. Advantages of the conventional approach are, firstly, it is accurate if the actual operating condition is the same as the condition of measurements determining the coefficients of the formula and, secondly, it is simple to use since the total loss is calculated with a single formula which includes all losses in the above.

Disadvantage of the conventional approach is the fact that accuracy is never be guaranteed if the measurement condition does not match to the actual operating condition. Those undesirable situations are not rare in actual machines, especially, in advanced machines such as a traction motor of EVs. Those advanced machines are fed with higher current than of the conventional machines to achieve high power density so that the lamination steel is magnetically highly saturated and this does not satisfy the measurement condition. Also, those advanced machines are controlled with inverter(s) employing Pulse Width Modulation (PWM) technique which generates high frequency minor loops on a fundamental major loop. The measurement condition does not include the minor loops and the resulting losses cannot represent the minor loop losses. The minor loops are generated not only by PWM but also by slot harmonics in a Permanent Magnet Synchronous Machine (PMSM) which is the main stream in EVs. Moreover, the measurement has limitation in frequency which actual frequency in a machine goes above the limitation. The disadvantage was not a significant problem because classical machines are designed to be operated with the low frequency sinusoidal waveforms of magnetic flux density.

To overcome the disadvantage, new models have been introduced for the hysteresis loss and the eddy current loss. The hysteresis loss is represented with Play-Hysteron model[1)] which is a semi-physical model and can reproduce a minor loop at an arbitrary operation point employing multiple static major loops. The eddy current loss is modeled by 1D-FEM[1)] in which eddy current distribution in thickness direction is solved with a conductivity of the steel sheet by one-dimensional FEM at each element of the main 2D/3D FEM. Note that since only conductivity is required, this method is valid for any frequency without limitation. Those two models give us significant improvements in accuracy for the advanced machines[3)]. A significant difference from the conventional approach is the fact that the new approach does not depend on measured losses and has wider applicability than the conventional approach.

However, the new approach misses the excess loss is inaccurate in case the excess loss is not ignorable. Although the best way to incorporate the excess loss is having a physical model, the phenomena are too complex to capture the mechanism. Currently, we are developing an expandable empirical based model as a second best. The new model shows reasonable performance for wide range even outside of the measurements. The detail will be explained in the presentation.

Reference

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3) K. Narita, H. Sano, T. Yamada, K. Aiso, K. Akatsu, “An Accurate Iron Loss Evaluation Method Based on Finite Element Analysis for Switched Reluctance Motors”, ECCE 2015