Experimentally established build factors for electromagnetic performance in a bonded NO20 stator stack

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2025

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Abstract

The electro-magnetic performance of the soft magnetic core in manufactured electric machines is known to deviate significantly from datasheet values for the material used in the core. We quantify the discrepancy in permeability and losses between datasheet and physical units by calculating build factors for a typical hairpin IPM traction machine design. The derived build factors for losses are typically 1.5 at high frequency below 1 T, while approaching unity at flux densities approaching 2 T for all tested frequencies. At low frequency and low flux density, the loss build factor is peaking at 4. Permeability build factor starts at 0.6 at low flux density, dips to 0.35 at 1 T, and reaches unity at 1.5 T. All data used for this research is made available in the public domain.

Introduction

The degradation of laminations during processing and stacking is well known, with many proposed methods for modeling [1], however data on modern high-performance laminations is scarce. We have designed, manufactured and tested an automotive traction machine stator, to observe its electromagnetic characteristics. The machine design features rectangular slots for a hairpin winding, and is optimized to be paired with an interior permanent-magnet rotor (IPM). Outer diameter is 170 mm, and stack length 165 mm. Three stator stacks are manufactured using laser cut and bonded NO20-1200h laminations from Sura HI-LITE [2] with a resulting stacking factor of 96%. After assembly, the stator stacks are measured using a Brockhaus BST-SA measurement system to characterize the magnetic performance in the stator coreback. Measurement results are analysed and compared with datasheet values with regards to magnetic polarization, permeability and losses. The discrepancy between measurements, u_m, and datasheet u_d for each quantity is quantified in terms of build factor F_b, as in equation 1.

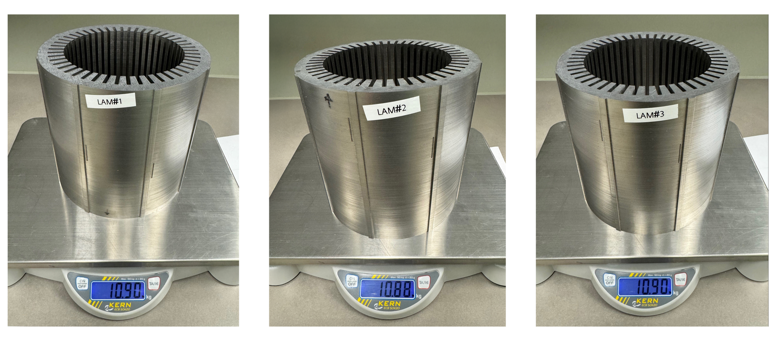

Figure 1: Three stator units used for measurements.

$$F_b = \frac{u_m}{u_d} \qquad (1) \qquad\qquad P_s = k_h B^{\alpha} f^{\beta} + k_e B^{\gamma} f^{\delta} \qquad (2)$$

A six-parameter Bertotti model [3], shown in eq. 2, is used to fit the loss data P_s across a wide range of excitation frequencies f, and peak magnetic flux densities B. This fitting is performed using the CMA-ES method provided by the package pymoo [4]. Two parameter sets are derived; datasheet losses, and measured stator losses. The measured stator losses from the three samples in figure 1 are arithmetically averaged per operating point before model fitting. Figure 2 shows the fitting data.

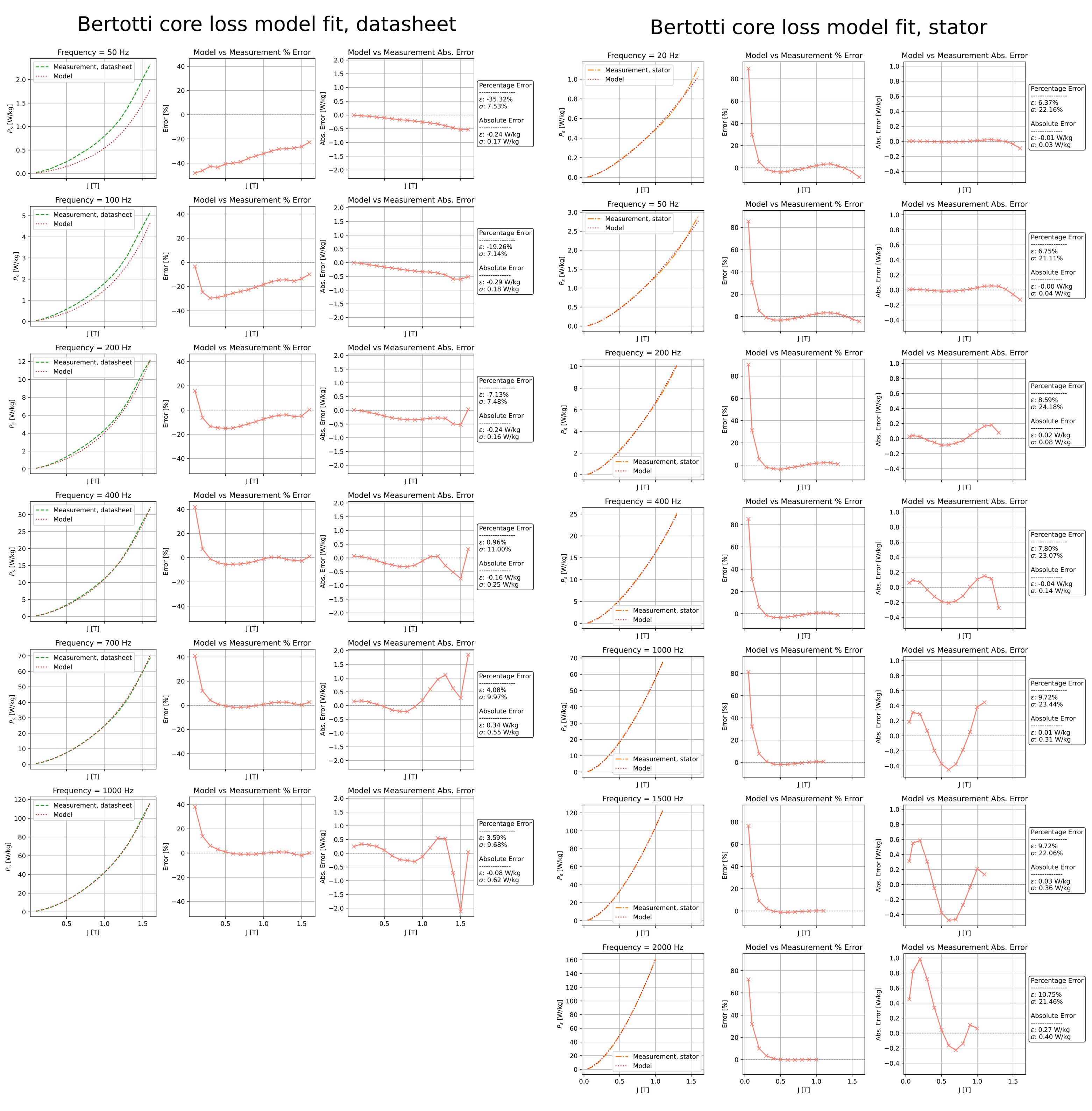

Figure 2: Model fitting for datasheet losses (left), and measured stator losses (right).

Results and discussion

The resulting fit for eq. 2 is poor for the datasheet loss data at 50 and 100 Hz, with errors of 20% or larger. For the stator data, the model fitting performs well across the entire frequency range, but a large deviation remains at flux densities below 0.2 T. This region of operation is less important in the context of permanently magnetized rotor machines.

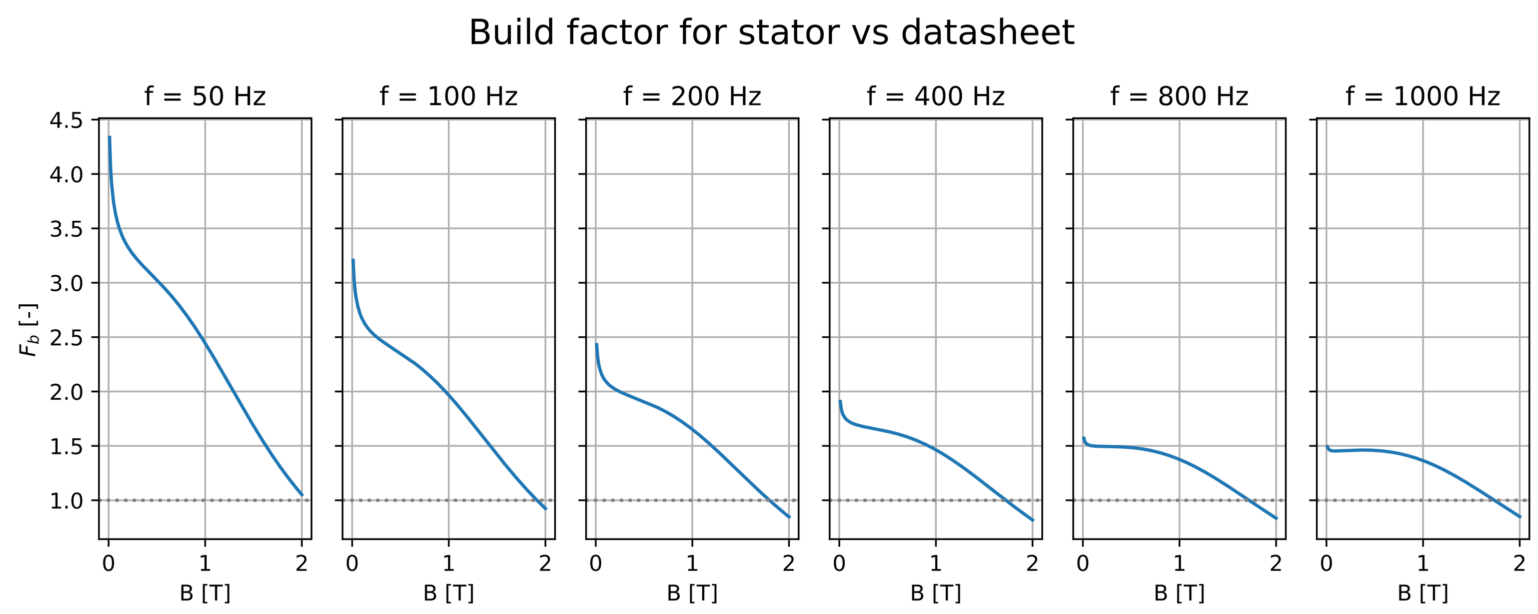

Figure 3: Build factors based on the models for datasheet and measurements losses presented in figure 2.

The Bertotti parameters obtained from the fitting procedure and used for calculation of the build factors are presented in Table 1. The numerically fitted parameters might not correlate with specific physical phenomena; however, it is notable that the γ parameter in the datasheet loss model is very large, and that the δ related to stator losses is very close to 1.

The resulting build factors for losses over a range of frequencies and flux densities are shown in figure 3. It appears that the measured losses at low frequency (50 Hz) and low flux densities (<1 T) are much larger than the datasheet values, resulting in a loss build factor of 2 to 4. However, at higher frequencies, the impact decreases and a build factor of 1.5 is observed from 800 - 1000 Hz and less than 1 T. For high flux densities, between 1 and 2 T, the build factor is trending towards unity across the tested frequencies.

Parameter	Datasheet	Stator
K_h	1.36e-03	2.81e-04
K_e	7.22e-04	2.36e-02
α	1.64e+00	1.74e+00
β	1.48e+00	1.71e+00
γ	4.66e+00	1.53e+00
δ	1.24e+00	9.84e-01

Table 1: Fitted parameters for eq. 2.

The dehysterized polarization curve from both measurements and datasheet is shown in figure 4. The relative permeability is calculated from the polarization data, and the permeability build factor is calculated as in eq. 1. All raw data, scripts and results are available through QR-code in figure 5.

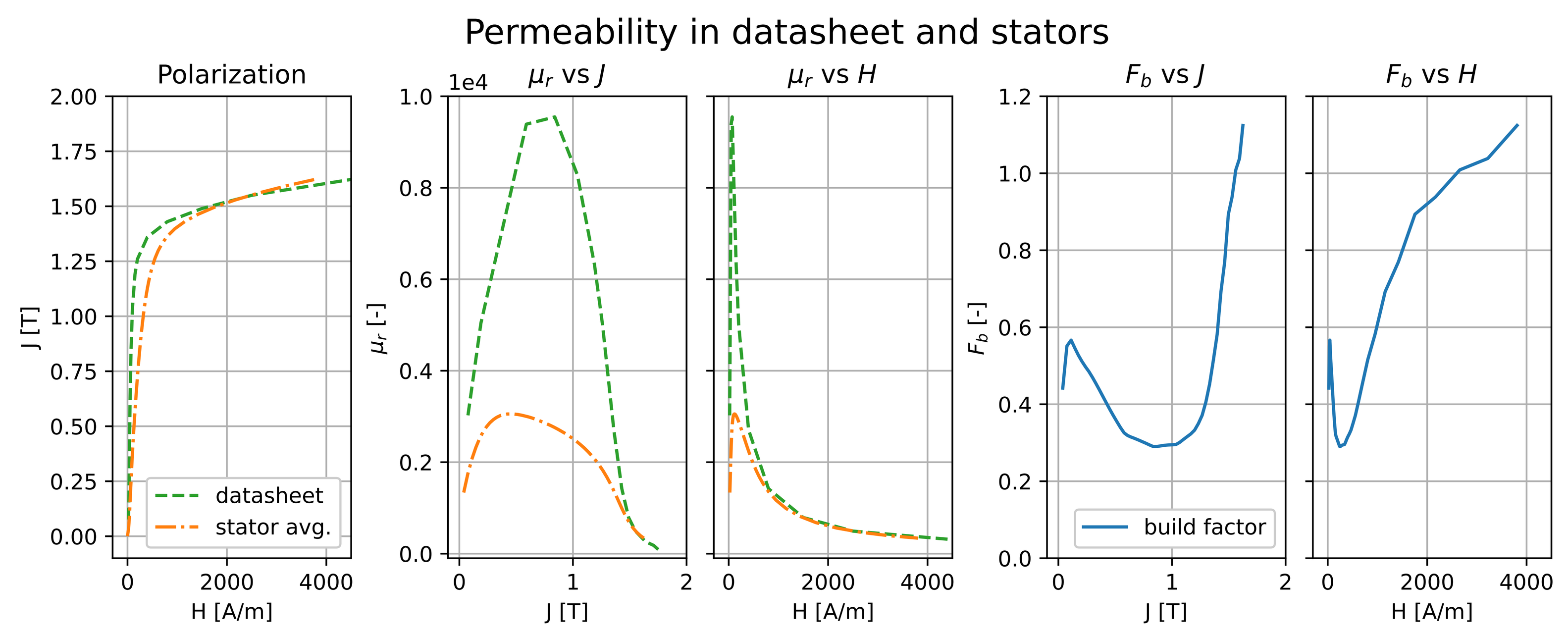

Figure 4: Resulting build factors for permeability based on the fitted data for datasheet and stator.

Conclusions

A loss build factor between 2 to 4 has been observed between datasheet and measurements on a bonded stator, but this occurs only between 0 and 1 T, and only for frequencies below 100 Hz. At higher frequencies the loss build factor appears to decrease, and at 1 kHz it is only 1.5 between 0 and 1 T. At 2 T the observed loss build factor reaches unity across the reported frequency span of 50 - 1000 Hz. A permeability build factor is between 0.35 and 0.6 at flux densities below 1 T. This factor tends towards unity between 1 and 1.5 T.

Figure 5: Link to data

References

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[4] J. Blank, "Cma-es." https://pymoo.org/algorithms/soo/cmaes.html, 2025. Documentation version 0.6.1.5. Accessed: 2025-08-28.