Characterizing a 1990's Jeep Wrangler Alternator's Drag Loss and Efficiency

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1. Introduction

Alternators have electromagnets which power the generator in a car. The combustion engine spins the pulley, and the magnetic flux drives a current through the phases to power systems like the air conditioning of a car. They can operate both as a motor and a generator. And, per their popularity in otherwise retired cars, alternators can be repurposed to build small renewable energy systems. Wind and running water may then be enough to supply a small home's energy needs. The alternator has three phases, a full bridge rectifier, and a voltage regulator. We stripped the alternator of the last two components.

2. Methods

2.1. Motor Tests

First, we tested the alternator as a motor. We powered the three phases through an Electronic Speed Control (ESC) with the lab's power supply. A speed dial allowed controlling the motor's speed. The electromagnets also need to be powered separately so that electricity can be made into kinetic energy. We also fed these with the power supply. We refer to this electricity as the rotor current. We measured the voltage across the ESC and the current through one of the phases, as well as the line-to-neutral back Electromotive Force (EMF) across one of the phases. We ran the motor at various rotor currents, each with many velocities controlled by the speed dial. The goal is characterizing the motor and drag constants at various rotor currents. From these velocities, we can extract the pulley's angular frequency, ω, in radians per second.

2.2. Generator Tests

Next, we tested it as a generator We spun the alternator's pulley with a drill press, varying the speed of the pulley through the tension in the belt connecting the alternator to the drill press motor. Similar to the motor procedure, we measured the line to neutral back EMF and fed the alternator a rotor current with a power supply. Additionally, the three phases united in a Wye configuration (separated by 2Ω resistors to avoid shorting the phases) and a 2Ω load connected the center node of the Wye to ground. This setup was also tested at various rotor currents, and each with various velocities of the pulley After measuring back EMFs for the motor in these two modes, we characterized the efficiency of the alternator. There were five parameters we needed to do this. Resistance coming from the power supply, resistance across each of the three phases, the back EMF constant, hysteresis loss and eddy current loss. After finding these parameters, we then calculated three important metrics: "gap" power, ohmic power loss, and drag power loss. The gap power, P_{gap}, is the amount of power transferred from the rotor to the stator, assuming full efficiency. It is found by multiplying frequency, torque constant,κ_τ , and stator current RMS, $i_{s,RMS}$;

$$P_{gap} = \omega \kappa_\tau i_{s,RMS}.$$

Ohmic power loss, P_{ohmic} is the power lost due to resistances in the alternator. It is found by adding the product of rotor current, i_r squared and power supply resistance, R_r, with the product of 3 times stator current squared times resistance across the three phases, R_s .

$$P_{ohmic} = i_r^2 R_r + 3 i_{s,RMS}^2 R_s$$

The last metric we calculated was drag power loss, P_{drag}, which is found by

$$P_{drag} = \omega C_0 + \omega^2 C_1$$

, where C_0 is the hysteresis loss coefficient and C_1 is eddy current loss coefficient.

2.3. Efficiencies

After finding these three metrics, we were able to find the motor and generator efficiencies. These will be defined as η_m and η_g, respectively. In both cases, $\eta = \frac{P_{out}}{P_{in}}$ where both are dependent on whether the alternator is being driven by a current as a motor, or by a torque on the pulley as a generator:

$$\eta_m = \frac{P_{gap} - P_{drag}}{P_{gap} + P_{ohmic}},$$

$$\eta_m = \frac{P_{gap} - P_{ohmic}}{P_{gap} + P_{drag}}.$$

2.4. Phases Wiring

It's worth noting that back EMF measurements from spinning the pulley by hand allowed us to note that the alternator was three-phase and the fourth connection was the neutral point. The relevant data is in the github which is linked in the comments.

3. Data & Results

Samples of the motor data as described in 2.1 are below:
Samples of the generator data as described in 2.2 are below:

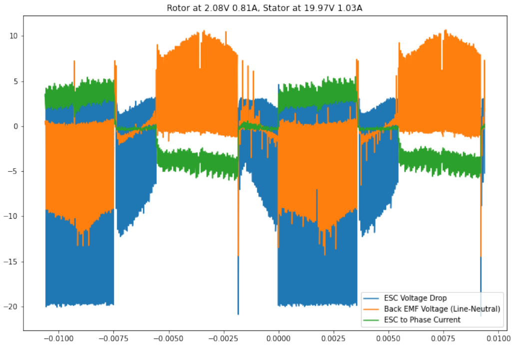

Figure 1: Higher stator current generator

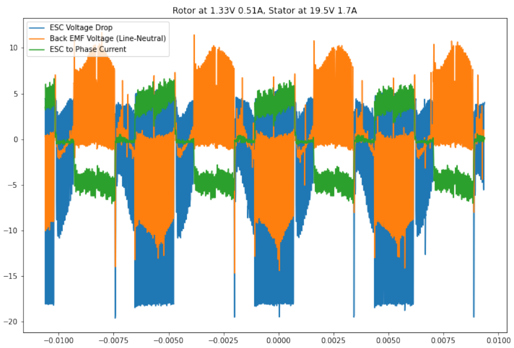

Figure 2: Lower stator current generator

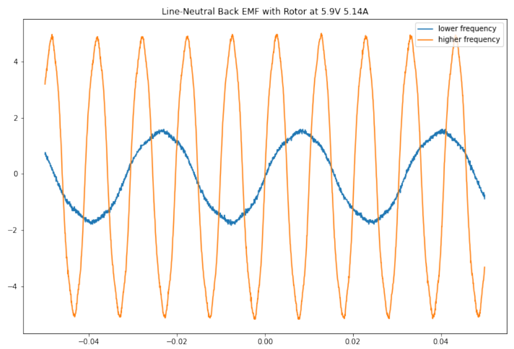

Figure 3: Higher stator current motor

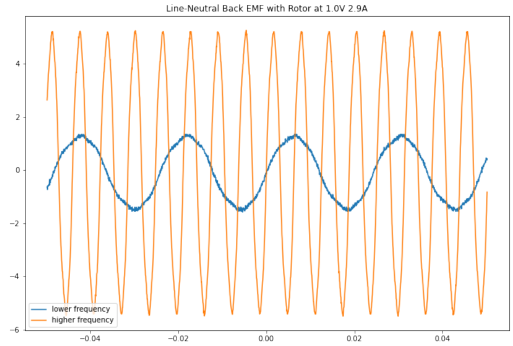

Figure 4: Higher stator current motor

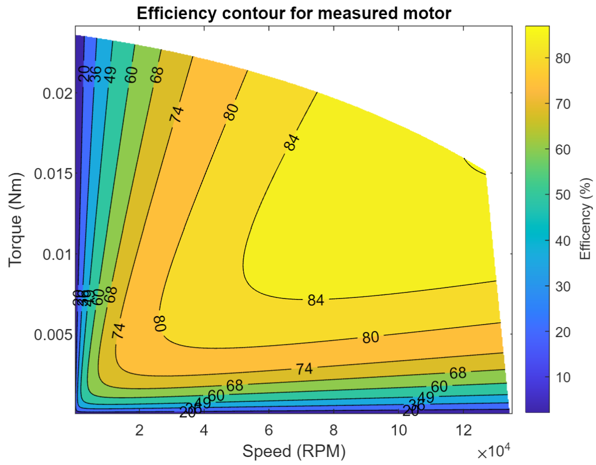

Figure 5: Aaron's ideal efficiency plot

4. Summary and conclusions

The data processing proved harder than expected. Wanting to emulate the efficiency plots of lab 3, we derived the drag coefficients, but often got negative or infinitesimal eddy current coefficients. Exploring whether this was due to our data or the code's inability to properly compute efficiency plots, we tried to duplicate the efficiency profile of the motor explored in lab 3.

In our opinion, the data collection was the problem as our code is able to generate proper efficiency plots given reasonable data. We were not able to fully characterize the efficiency profile of our alternator but the relation between the stator current and the strength of the magnetic field, which was then inversely related to spinning frequency of the pulley was clear. We remain confident that reused alternators can be used to help obtain renewable power from nature.

Acknowledgements

Thanks to Aaron and Steve for all their patience and support and the ideas that inspired this project. This will be

the first of many adventures with the alternator. The relevant notebooks and some of the data collected can be found at https://github.com/elsirdavid/AlternatorTests.

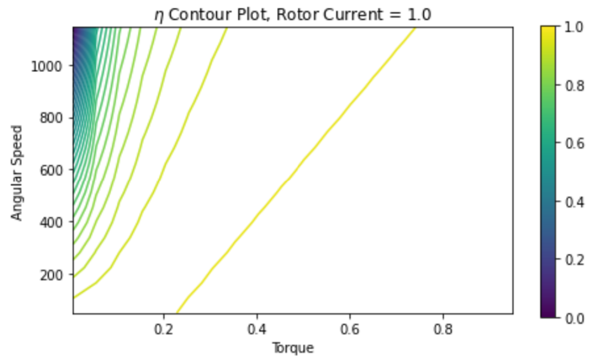

Figure 6: Original data-based efficiency plots

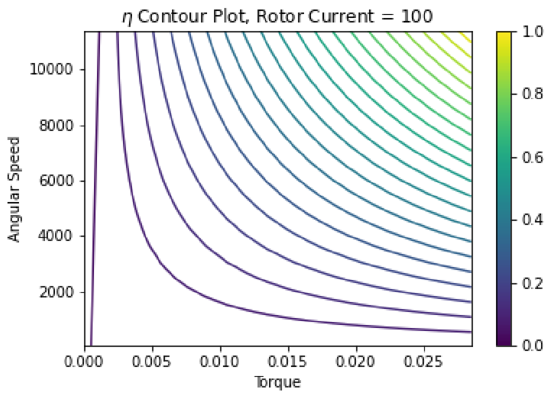

Figure 7: Synthetic data-based efficiency plots