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Stall Burst Thermal Model Manual

Revision 0.4

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1. Introduction

To improve functionality at stall and low speed, a thermal model has been implemented to allow for real time estimation of inverter switch junction temperature. This model allows for higher bursts of current from stall in a wide array of conditions while continuing to protect the inverter for long term use.

This methodology is implemented in the form of an inverter switch Junction Temperature model fed into a PI regulator targeting a max switch junction temperature of ~150 ^{O}C. This regulator allows the inverter to have the full max burst current, as found by testing at Cascadia Motion, then the Junction Temperature Model and PI regulator derate that max burst current as necessary to maintain a max junction temperature of ~150 ^{O}C.

The Junction Thermal Model takes in: DC voltage in Vdc, switching frequency in Hz, motor speed in rpm, motor current in Apk, and coolant temperature in ^{O}C, to predict the hottest inverter switch junction temperature in ^{O}C. Note: the model will change over time, but time is not an inherent input to the system other than the switching period.

The general architecture of control is presented below in Figure 1.

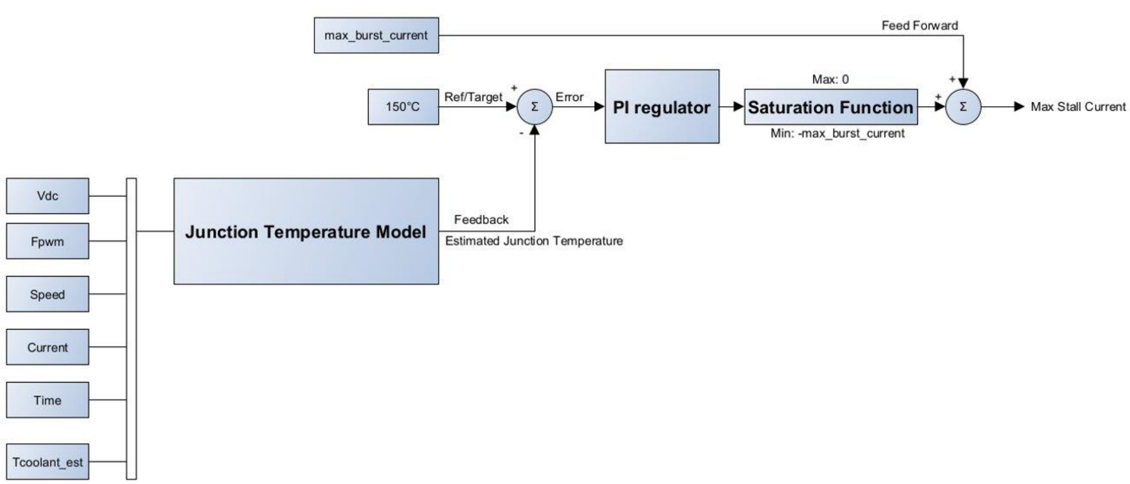

Figure 1. General architecture of Stall Burst Thermal Model.

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Through this methodology, compared to a steady state model, more current is allowed at stall for a transient burst, assuming the inverter switch junction temperature is not already at its maximum rating of ~150 ^{O}C.

2. Implementation

2.1 Overview

The Stall Burst Thermal Model is implemented in the code base only for specific inverters. These inverters are listed in the table below. No user input is required to utilize the model and its resulting stall burst.

Stall Burst Thermal Model Inverters	Firmware Version
CM200DX	6522 and later
CM200DZ	6527 and later
CM350DZ	6527 and later

2.2 Stall Burst Thermal Model Settings

There are no required user inputs to activate the Stall Burst Thermal Model outside of using the appropriate inverter.

However, it is highly recommended to limit the torque ramp rate of the system (via EEPROM Torque_Rate_Limit_EEPROM_(Nm)_x_10) to no more than 70 Nm/3ms or a setting of 700 for iM225 and iM375 integrated modules. This corresponds to a torque ramp rate of ~ 23,000 Nm/s. Rates faster than this may cause stability issues.

There are three new signals relayed over CAN which report the highest junction temperature reported by the model ^{O}C, whether Burst Model Mode is stall or not, and whether the Stall Burst Thermal Model is limiting or not. These messages can be used to monitor the operation of this control mode. These messages, INV_Stall_Burst_Model_Temp, INV_Burst_Model_Mode (0 = stall and 1 = high speed), and INV_Limit_Stall_Burst_Model (1 = On/Limiting and 0 = Off) respectively, are in the latest CAN iM-225 DBC file.

2.3 CM200DX Stall Burst Performance

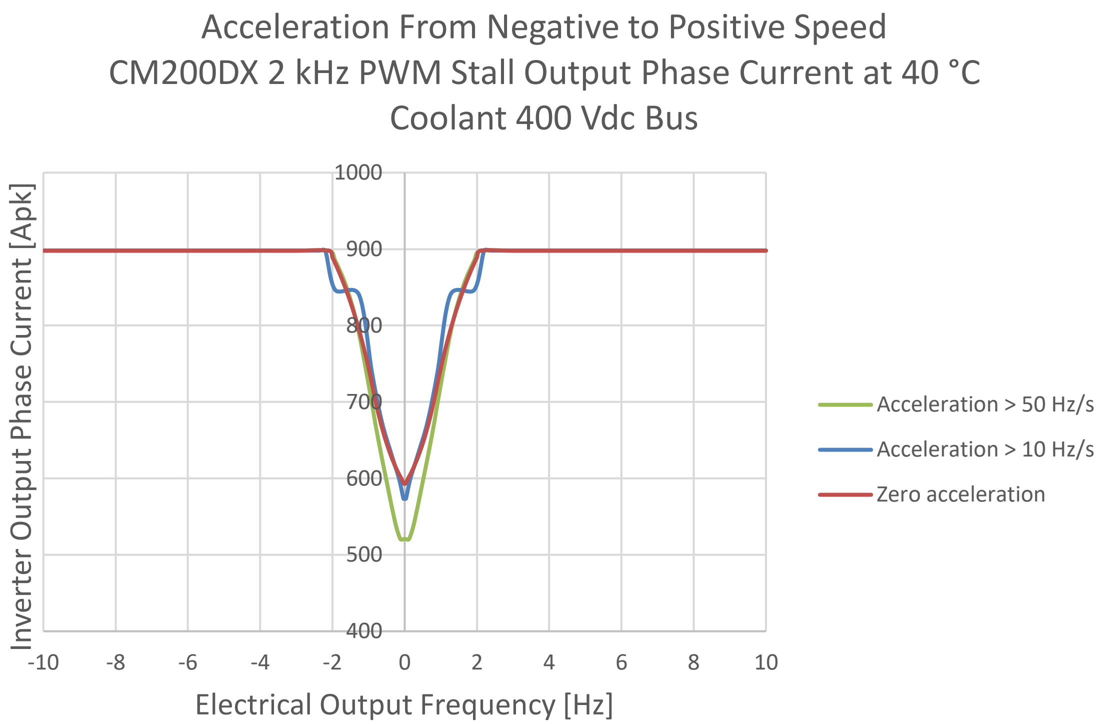

Figure 2. CM200DX Stall Output Phase Current vs Electrical Output Frequency

The above figure reflects what happens when a vehicle rolls back some then accelerates forward more than 10 Hz/s and 50 Hz/s. Performance at various constant electrical output frequencies is also shown for comparison. CM200DX performance when accelerating can be worse than constant output frequency performance. This is due to current undershoot caused by the Stall Burst Thermal Model PID when current distribution is shifting between the three motor phases at different rates. Vehicles rarely have true zero acceleration when full torque is commanded due to driveline slop. Therefore, performance with acceleration better represents typical performance.

Results will vary depending on the initial rotor position because different rotor positions have different distributions of current in each phase. The above figure represents worst case initial rotor position. Sometimes rolling back slightly when on an incline can help low speed performance by changing the rotor initial position.

If held at zero speed the steady state current is 592.7 Apk for 120 seconds. Current will reduce further to as low as 223 Apk due to hot spot limiting after 120 seconds.

At zero speed phase current is DC, and Apk current can be divided by $\sqrt{2}$ to get an equivalent Arms value that can be used for looking up motor torque values at a current that is typically listed in Arms.

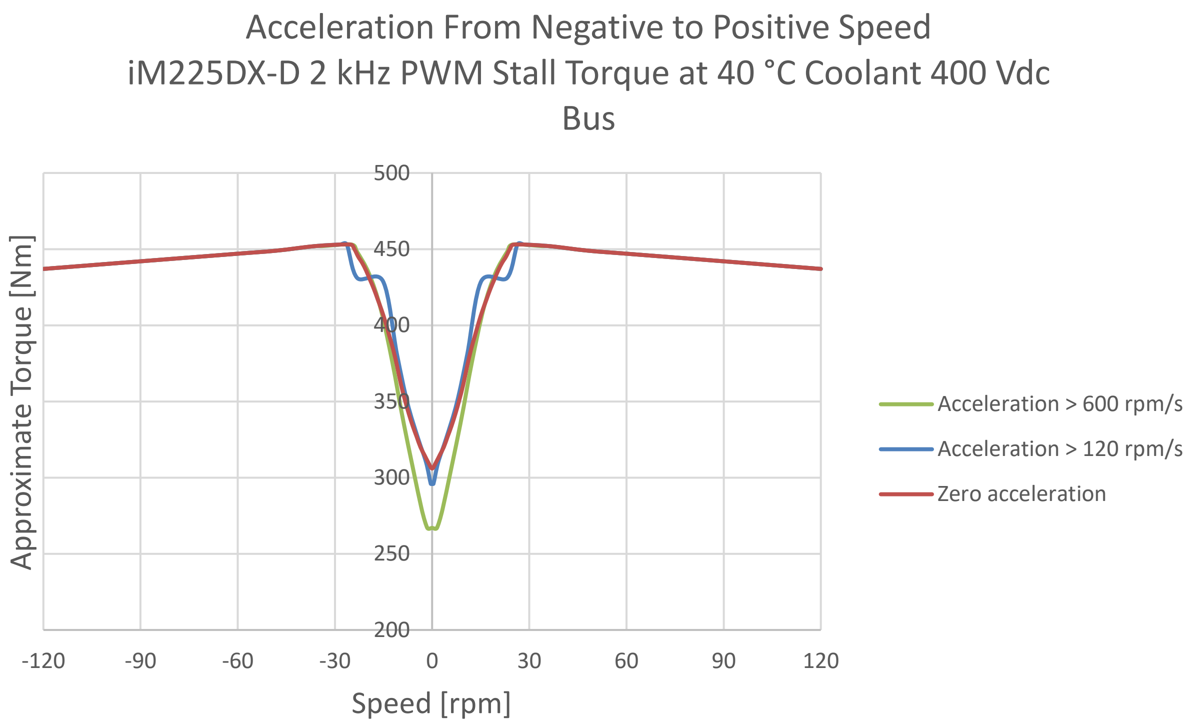

Figure 3. iM225DX-D Stall Torque vs Speed

2.4 CM200DZ Stall Burst Performance

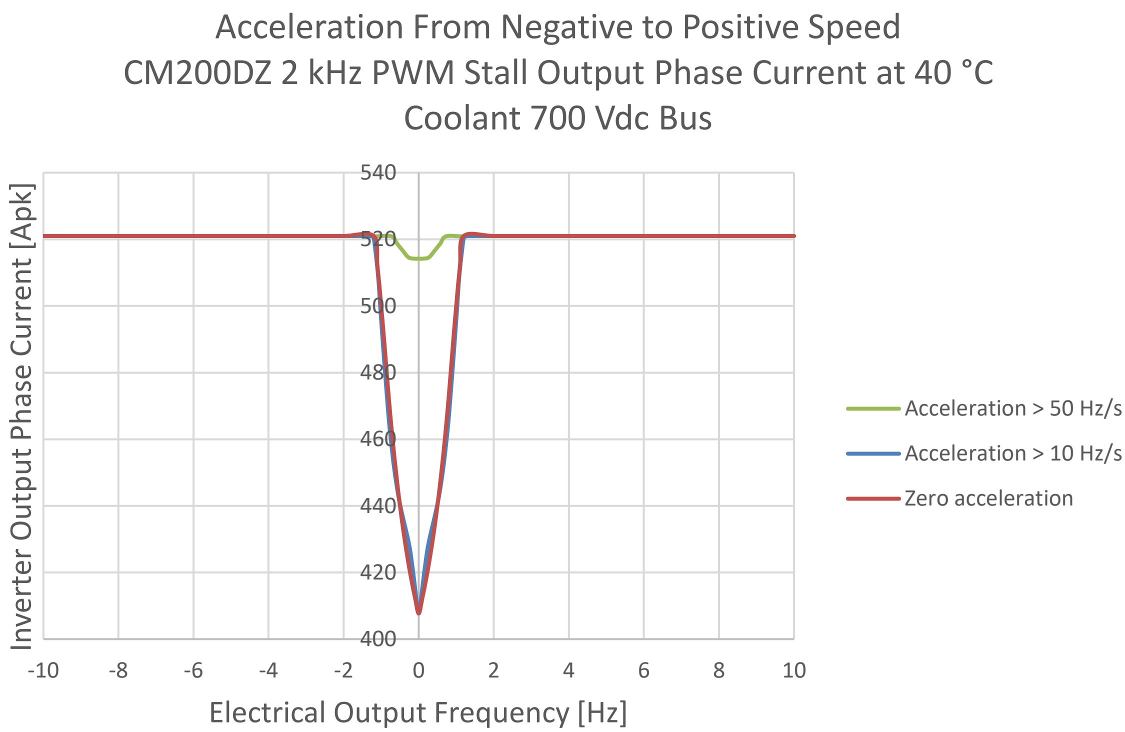

Figure 4. CM200DZ Stall Output Phase Current vs Electrical Output Frequency

The above figure reflects what happens when a vehicle rolls back some then accelerates forward more than 10 Hz/s and 50 Hz/s. Performance at various constant electrical output frequencies is also shown for comparison. CM200DZ performance when accelerating can be better than constant output frequency performance. CM200DZ does not have the same current undershoot that CM200DX has. Rolling back and accelerating forward minimizes duration at zero speed resulting in better performance while passing through zero speed. Rolling back and ramping torque during the rollback results in better performance because torque is ramping while spinning which results in a lower initial temperature when entering zero speed. Power module junction temperature rises faster and higher when torque is slowly ramped at zero speed instead of when motor is pinning. Vehicles rarely have true zero acceleration when full torque is commanded due to driveline slop. Therefore, performance with acceleration better represents typical performance.

Results will vary depending on the initial rotor position because different rotor positions have different distributions of current in each phase. The above figure represents worst case initial rotor position.

If held at zero speed the steady state current is 407.7 Apk for 47 seconds. Current will reduce further to as low as 272 Apk due to hot spot limiting after 47 seconds.

At zero speed phase current is DC, and Apk current can be divided by $\sqrt{2}$ to get an equivalent Arms value that can be used for looking up motor torque values at a current that is typically listed in Arms.

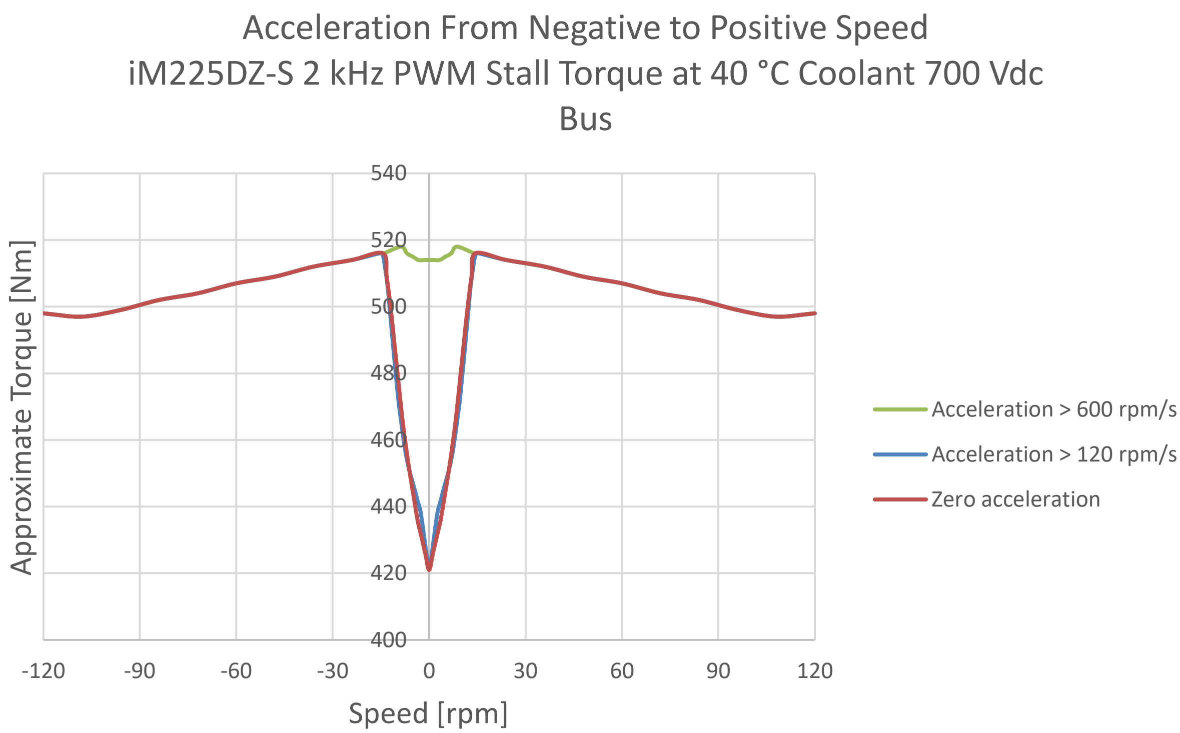

Figure 5. iM225DZ-S Stall Torque vs Speed

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2.5 *CM350DZ Stall Burst Performance*

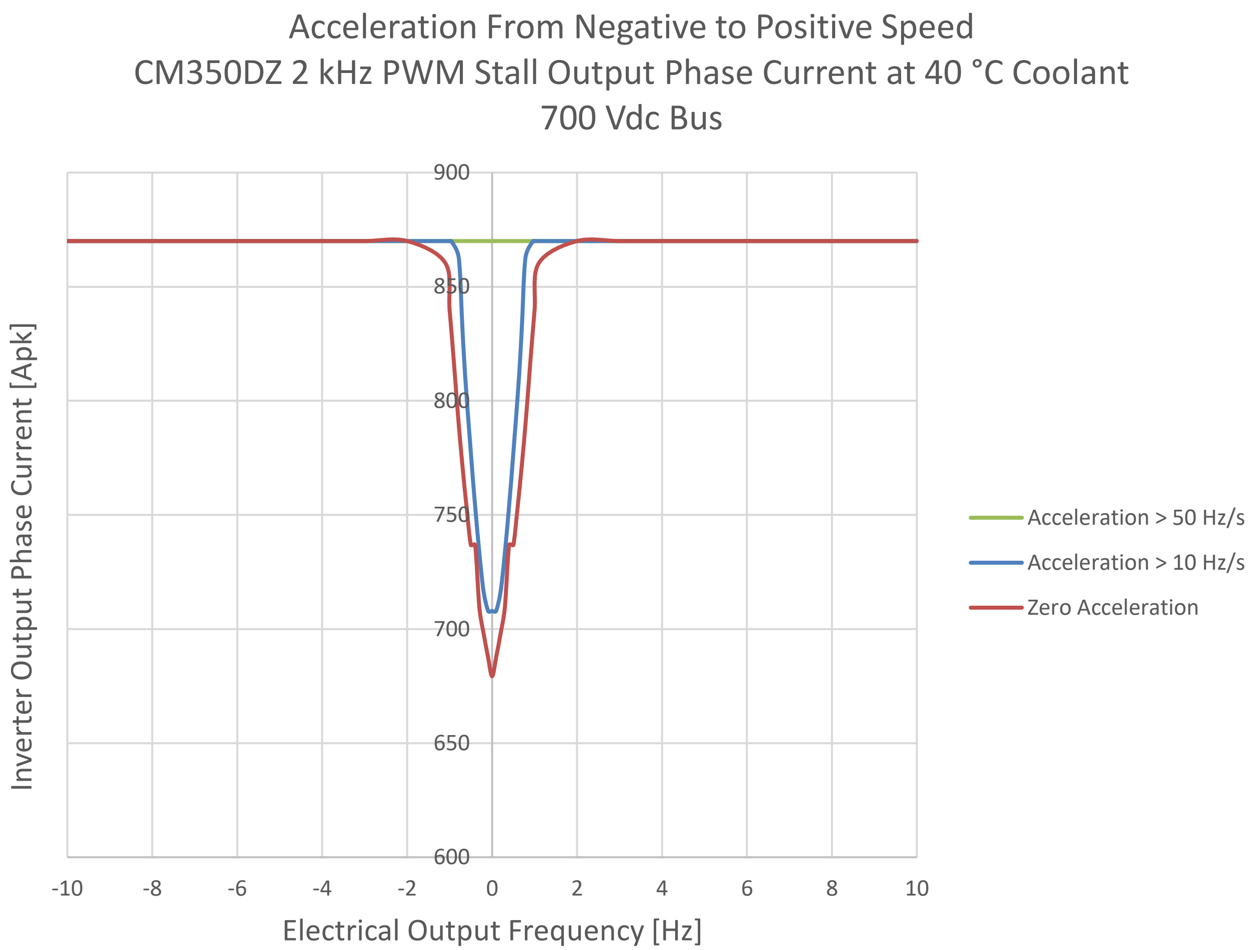

Figure 6. CM350DZ Stall Output Phase Current vs Electrical Output Frequency

The above figure reflects what happens when a vehicle rolls back some then accelerates forward more than 10 Hz/s and 50 Hz/s. Performance at various constant electrical output frequencies is also shown for comparison. CM350DZ performance when accelerating can be better than constant output frequency performance. CM350DZ does not have the same current undershoot that CM200DX has. Rolling back and accelerating forward minimizes duration at zero speed resulting in better performance while passing through zero speed. Rolling back and ramping torque during the rollback results in better performance because torque is ramping while spinning which results in a lower initial temperature when entering zero speed. Power module junction temperature rises faster and higher when torque is slowly ramped at zero speed instead of when motor is pinning. Vehicles rarely have true zero acceleration when full torque is commanded due to driveline slop. Therefore, performance with acceleration better represents typical performance.

Results will vary depending on the initial rotor position because different rotor positions have different distributions of current in each phase. The above figure represents worst case initial rotor position.

If held at zero speed the steady state current is 679.3 Apk for 106 seconds. Current will reduce further to as low as 655 Apk due to hot spot limiting after 106 seconds.

At zero speed phase current is DC, and Apk current can be divided by $\sqrt{2}$ to get an equivalent Arms value that can be used for looking up motor torque values at a current that is typically listed in Arms.

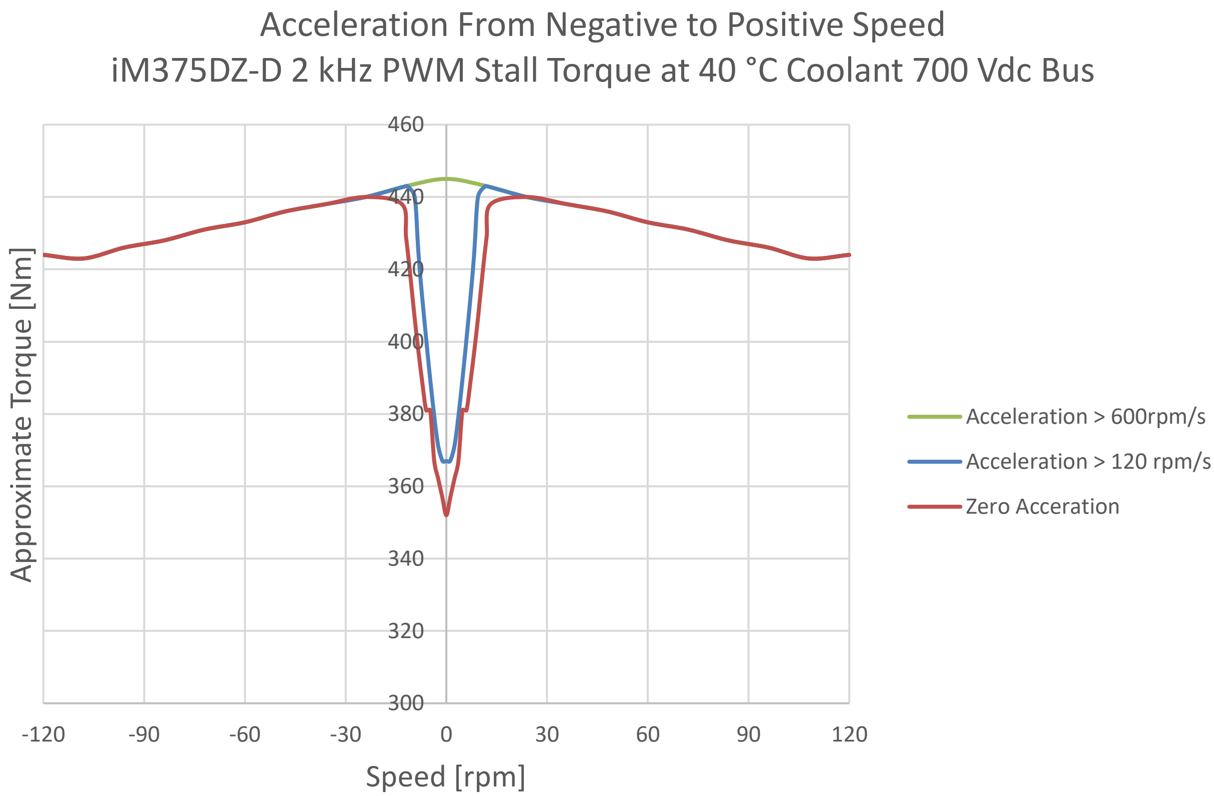

Figure 7. iM375DZ-D Stall Torque vs Speed

Figure 8. iM425DZ-D Stall Torque vs Speed

Revision History

Version	Description of Versions / Changes	Responsible Party	Date
0.1	Initial version.	Christian Tigges and Andrew Louie	7/16/2022
0.2	Added CM200DX stall performance information.	Andrew Louie	1/10/2023
0.3	Added CM200DZ stall performance information. Added CM350DZ stall performance information.	Andrew Louie Christian Tigges	3/27/2023
0.4	Corrected CM200DX stall performance values and plots. Corrected CM200DZ stall performance values and plots. Corrected CM350DZ stall performance values and plots.	Andrew Louie	5/23/2023