## Final Report

## Testing of 5x Adventech Motors in Florence AL June 14-18, 2021

By R.G. Smiley, PE July, 2021

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### Background

During the Winter of 2021, performance testing on 3x motors (40HP/2P, 45HP/4P, and 45HP/6P) was done at Advanced Energy. MDS Inc. was contracted in the Spring of 2021 by Adventech to perform performance testing of a total of 5x motors at the Adventech site in Florence, AL, and to assist where practical in the process of obtaining certain safety certifications (UL, CE, etc.) for the family of motors. MDS testing, and safety testing to UL-1004-1 by Intertek, Inc. were performed during the week of June 14, 2021. Subsequent environmental and lifting hook testing was performed on a representative sample motor at Intertek.

The MDS effort was to apply standard motor testing methodology, specifically IEEE-112/2017 Part 7.3.2.3 Method 2—Acceleration [2], along with determination of losses) to assess the performance of Adventech motors. Aspects of an installed Adventech "motor system", for example behavior while having more than one motor is connected as is done in the Adventech demonstrator, were not tested or assessed by MDS during this effort.

### Testing Performed

Two motors were tested while loaded on an existing Adventech A&W water brake dynamometer. Power was supplied by a Jenkins variable-tap power supply owned by Adventech. Intertek witnessed this testing and collected some of their own data, primarily thermal readings at ~12 locations on 2x motors during heat runs. MDS independently monitored the bulk winding temperature of the 2x motors during heat runs. MDS also, independently of the dyno, performed uncoupled starts on all 5x motors using MDS instrumentation to obtain performance curves using patented MDS technology (US Patent 10,698,031) and in accordance with IEEE-112 [2] as mentioned above.

The 480V, 3P Motors tested by MDS were:

40 HP, 2-Pole
45 HP, 4-Pole
45 HP, 6-Pole
150 HP, 4-Pole
175 HP, 8-Pole

Results Obtained

1. While on-site, the results of testing the 45HP/6P motor were analyzed in detail and found to closely match the performance test results from Advanced Energy, which in turn closely matched the curves in Adventech datasheets, see Fig. 1. Subsequent analysis was performed the remaining 4 motors to obtain similar results, which are presented later.

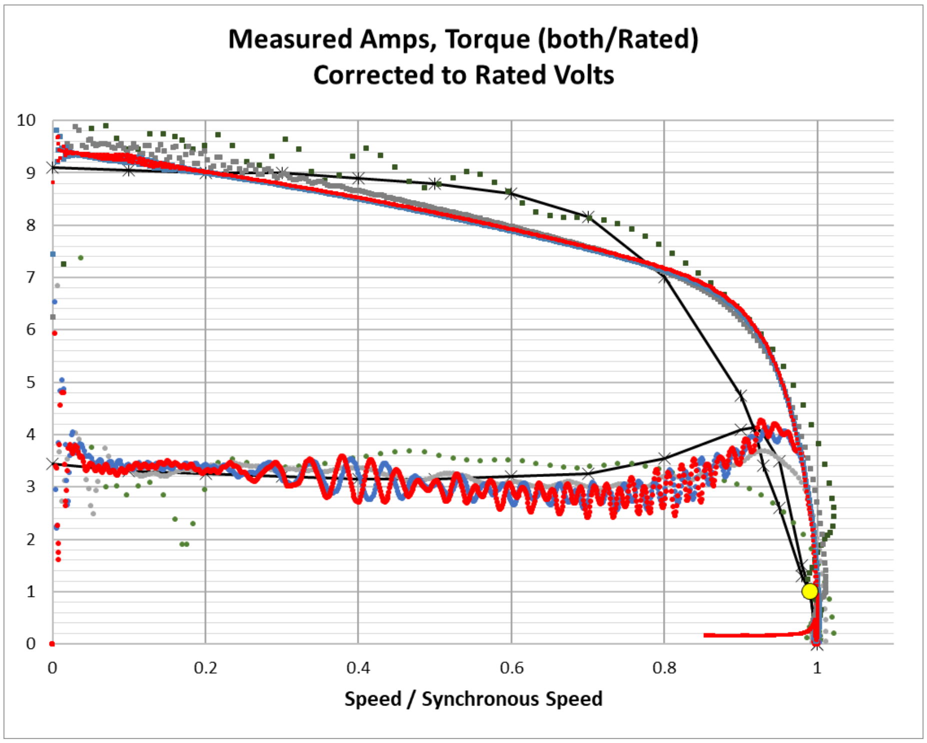



Fig 1 – Per unit Amps (upper curves) and Torque (Accel * Inertia, lower curves) vs speed for the 45 HP/6P motor. This data is from several across the line starts at various voltages from ~120 to 480V, all corrected to rated Voltage. The solid black line is from the Adventech data sheet.

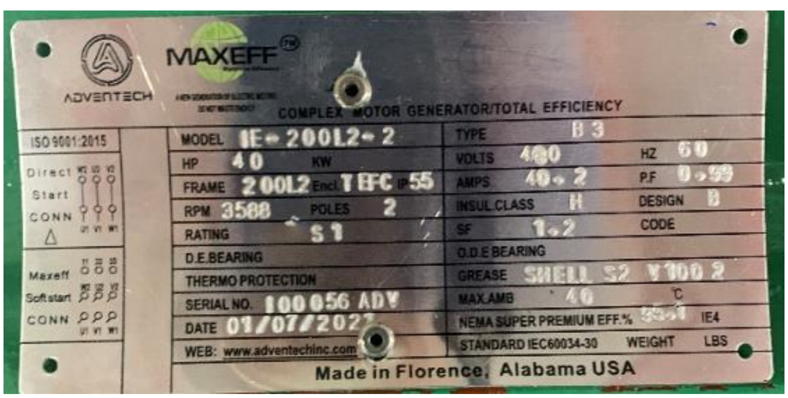
2. MDS monitoring of the dyno testing generally matched the readings from Adventech instrumentation on the dyno and Jenkins power supply.
3. As advertised, the Adventech motors do indeed exhibit unity power factor at rated load, as well as higher power factor during a transient start, than typical induction motors.
4. Thermal runs on two motors indicate a temperature rise under load, roughly consistent with a Class A insulation system requirement.
5. The 2x larger motors (150HP/4P and 175HP/8P) have atypical behavior during a no-load, open-circuit power off event, specifically exhibiting ~20% motor terminal voltage surge above running line voltage lasting several seconds. The same phenomenon is present but barely observable in the 3x smaller motors.
6. No testing with inverter power supply, was performed during this effort.
7. Offline, 4-wire winding resistance testing was performed on all 5x motors.

8. Efficiency results were obtained for the 5 motors, and presented below.

**Test Setup and Motors Tested**

Left, a 360ppr incremental encoder attached to the free shaft end via magnetic coupling, was used for high-resolution speed measurement during uncoupled start tests. Right, typical mounting arrangement on Adventech test table, and Adventech thermocouple placement on cooling fin of 150HP/4P motor.

Below are the nameplates of 5x tested motors.



40HP/2P

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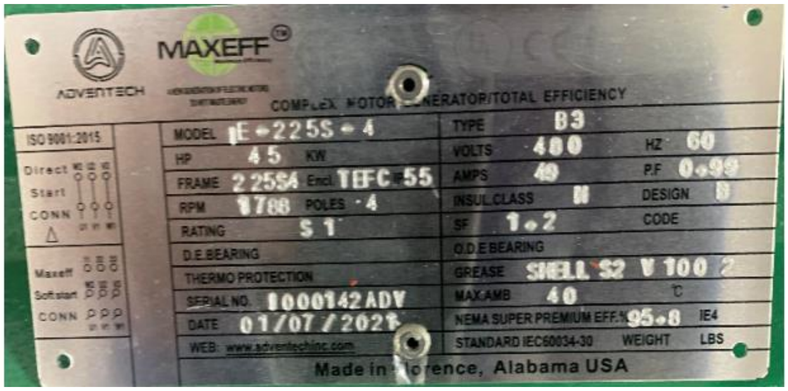
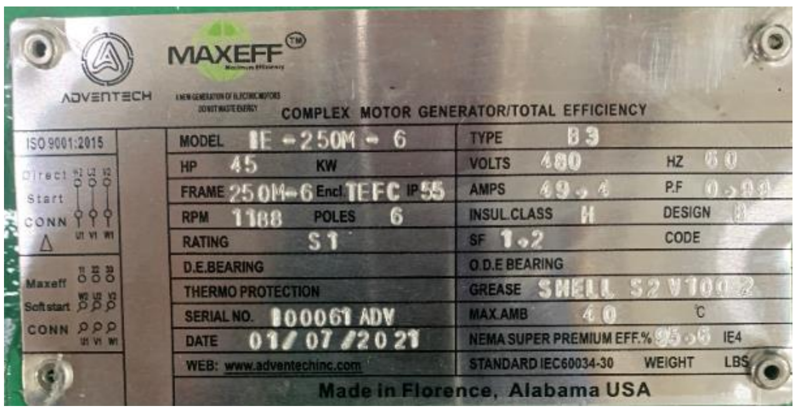
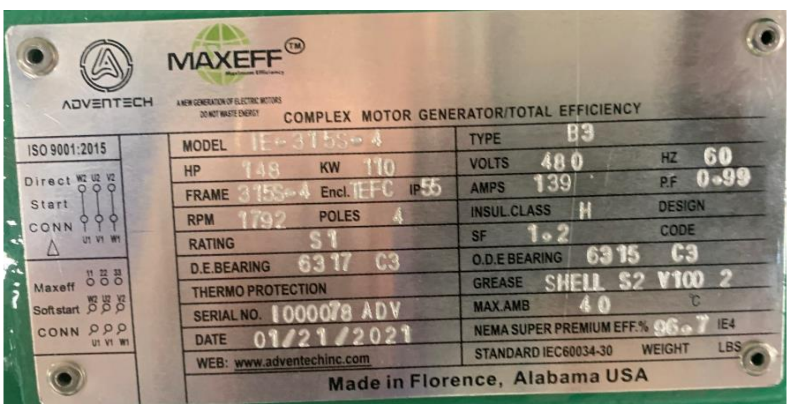


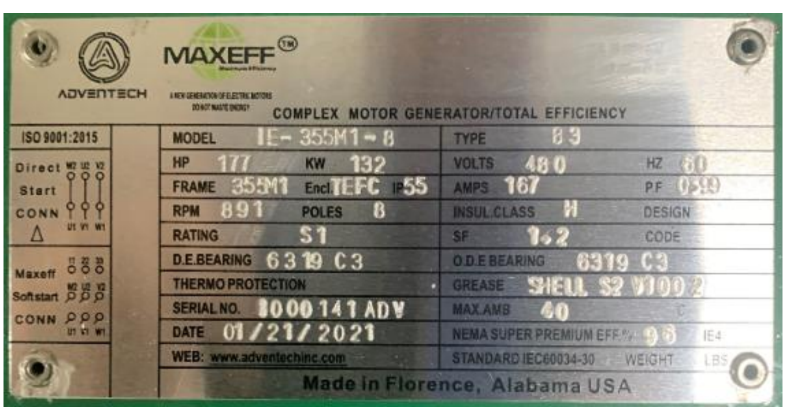

45HP/4P




45HP/6P




150HP/4P

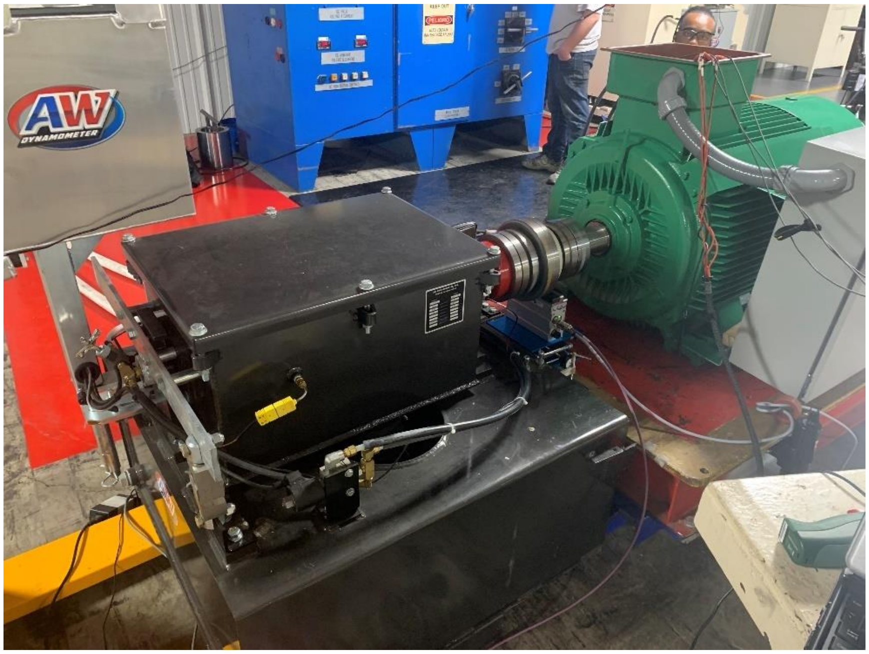



175HP/8P

| | 40HP/2P | 45HP/4P | 45HP/6P | 150HP/4P | 175HP/8P | Comment |
|---|---|---|---|---|---|---|
| **Nameplate Data** **Model** | IE-200L-2 | IE-225S-4 | IE-250M-6 | IE-315S-4 | IE-355M1-8 | |
| Rated Volts | 480 | 480 | 480 | 480 | 480 | |
| Rated Amps | 40.2 | 49 | 49.4 | 139 | 167 | |
| Rated RPM | 3588 | 1788 | 1188 | 1792 | 891 | |
| Rated HP | 40 | 45 | 45 | 148 | 177 | |
| PF | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | |
| Poles | 2 | 4 | 6 | 4 | 8 | |
| Rated Torque, Nm | 79 | 179 | 269 | 588 | 1413 | |
| Efficiency | 95.1 | 94.0 | 95.6 | 97.4 | 96.1 | From motor drawing |
| Starting Current ratio | 7.6 | 9.6 | 7.1 | 7.0 | 6.8 | From motor drawing |
| Starting Torque Ratio | 3.3 | 2.5 | 2.1 | 2.2 | 2.0 | From motor drawing |



Jenkins Motor Test Center, a multi-tap 480:X transformer having fixed-voltage taps at 60, 120, 240, and 480 Vrms was used for all across-the-line, constant-frequency uncoupled starts. Output can further be adjusted by setting +/-10% of nominal center tap voltage. For dyno tests, the Adventech setup was as below.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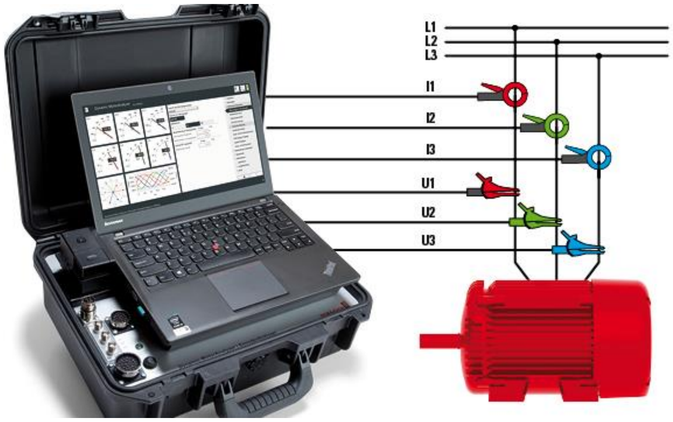
DYNAMOMETER

**MDS Test Equipment Used**

1. Schleich Dynamic Motor Analyzer (DMA), SN 14149, Cal due date 24-Mar-2022, used for voltage, current, and speed measurements




2. Schleich Motor Analyzer (MA2), Calibration due date 29-Jun-2022, used for static 4-wire measurements of 3P winding resistance

3. Fluke 289 True RMS DVM, SN 423900002, Cal due date 15-Apr-2022, used for voltage measurements in parallel with DMA

4. AEMC 675 , SN 3756/MKCT, Cal due date 11-Mar-2021, used for current measurements in parallel with DMA


5. MDS-17 Calibration Resistor Kit, Calibration due date 26-Feb-2023, used to validate MA2 on-site.

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## Detailed Results

### 1. DC Winding Resistance in Ohms, line-to-line, room temperature

| | R12 | R23 | R31 | Ravg | %Deviation |
|---|---|---|---|---|---|
| 40HP/2P | 0.1340 | 0.1390 | 0.1390 | 0.1373 | 2.4% |
| 45HP/4P | 0.1660 | 0.1660 | 0.1660 | 0.1660 | 0.0% |
| 45HP/6P | 0.1680 | 0.1690 | 0.1680 | 0.1683 | 0.4% |
| 150HP/4P | 0.0337 | 0.0335 | 0.0338 | 0.0337 | 0.4% |
| 175HP/8P | 0.0339 | 0.0339 | 0.0339 | 0.0339 | 0.1% |

Table 1, Stator winding resistances from 4-wire resistance method

### 2. Temperature runs

Temperature runs were not performed on all motors.

| Motor | 175HP/8P | | | **Minutes** | **R12 mOhms** | **R23** | **R31** | **Ravg** | **dWindingC** | **Flange F** | **Flange C** | **dFlangeC** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | 50% | 74KW | | 0 | 33.913 | 33.897 | 33.855 | 33.888 | 0.00 | 82.7 | 28.16667 | 0 |
| | | | | 10 | 34.48 | 34.41 | 34.46 | 34.450 | 4.22 | 83 | 28.33333 | 0.166667 |
| | | | | 20 | 35 | 34.97 | 35.04 | 35.003 | 8.37 | 85.3 | 29.61111 | 1.444444 |
| T = Tr(1-exp(-t/TC)) | | | | 30 | 35.33 | 35.23 | 35.44 | 35.333 | 10.85 | 87.7 | 30.94444 | 2.777778 |
| Tr | 24.11541 | degC | | 40 | 35.57 | 35.66 | 35.65 | 35.627 | 13.05 | 90 | 32.22222 | 4.055556 |
| TC | 50.36305 | min | | 50 | 35.8 | 35.92 | 35.87 | 35.863 | 14.83 | 92.3 | 33.5 | 5.333333 |
| | | | | 60 | 36.13 | 36.1 | 36.14 | 36.123 | 16.78 | 94 | 34.44444 | 6.277778 |
| | | | | 70 | 36.31 | 36.27 | 36.43 | 36.337 | 18.38 | 95.9 | 35.5 | 7.333333 |
| | | | | 80 | 36.53 | 36.29 | 36.45 | 36.423 | 19.03 | 97.2 | 36.22222 | 8.055556 |
| | | | | 90 | 36.72 | 36.53 | 36.48 | 36.577 | 20.19 | 98.7 | 37.05556 | 8.888889 |

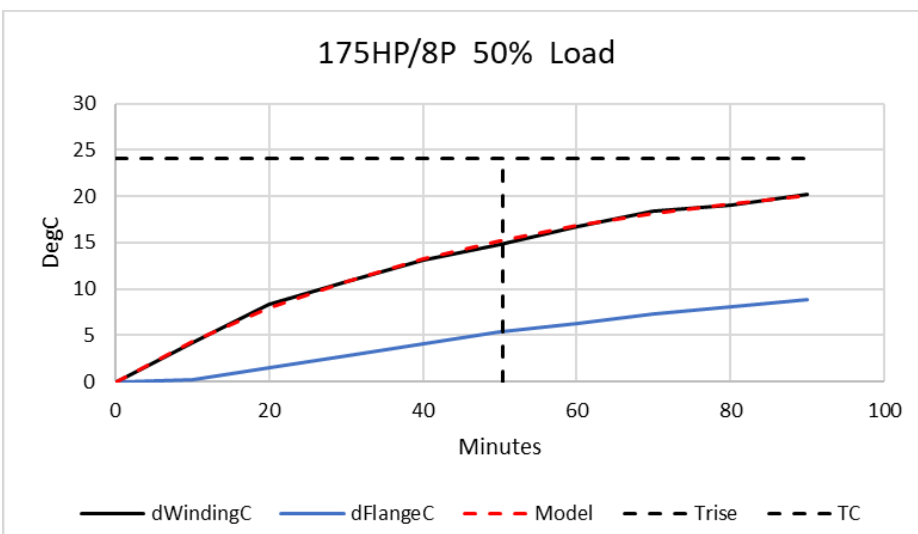


Fig 2.1, Temperature run data on 175HP/8P motor at ~50% load

(Adventech dyno capacity restricted long-term loading for this motor)

| Motor | 150HP/4P | | | Minutes | R12 | R23 | R31 | Ravg | dWindingC | Flange F | Flange C | dFlangeC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | 106% | 118KW | | 0 | 36.695 | 33.762 | 33.545 | 34.667 | 0.00 | 86.3 | 30.16667 | 0 |
| | | | | 10 | 35.877 | 35.629 | 35.61 | 35.705 | 7.62 | 90.9 | 32.72222 | 2.555556 |
| | | | | 20 | 36.558 | 36.24 | 36.39 | 36.396 | 12.69 | 97.2 | 36.22222 | 6.055556 |
| T = Tr(1-exp(-t/TC)) | | | | 30 | 36.94 | 36.98 | 36.82 | 36.913 | 16.49 | 102.5 | 39.16667 | 9 |
| Tr | 40.32807 | degC | | 40 | 37.84 | 37.41 | 37.57 | 37.607 | 21.57 | 106.6 | 41.44444 | 11.27778 |
| TC | 52.31838 | min | | 50 | 38.42 | 38.27 | 38.14 | 38.277 | 26.49 | 109.8 | 43.22222 | 13.05556 |
| Sumsq Err | 2.720285 | | | 60 | 38.3 | 38.5 | 38.3 | 38.367 | 27.15 | 112.3 | 44.61111 | 14.44444 |
| | | | | 70 | 38.72 | 38.59 | 38.57 | 38.627 | 29.06 | 114.7 | 45.94444 | 15.77778 |
| | | | | 80 | 39.05 | 38.8 | 38.82 | 38.890 | 30.99 | 116.3 | 46.83333 | 16.66667 |
| | | | | 90 | 39.45 | 39.27 | 39.35 | 39.357 | 34.42 | 117.7 | 47.61111 | 17.44444 |
| | | | | 100 | 39.38 | 39.3 | 39.14 | 39.273 | 33.81 | 119.6 | 48.66667 | 18.5 |

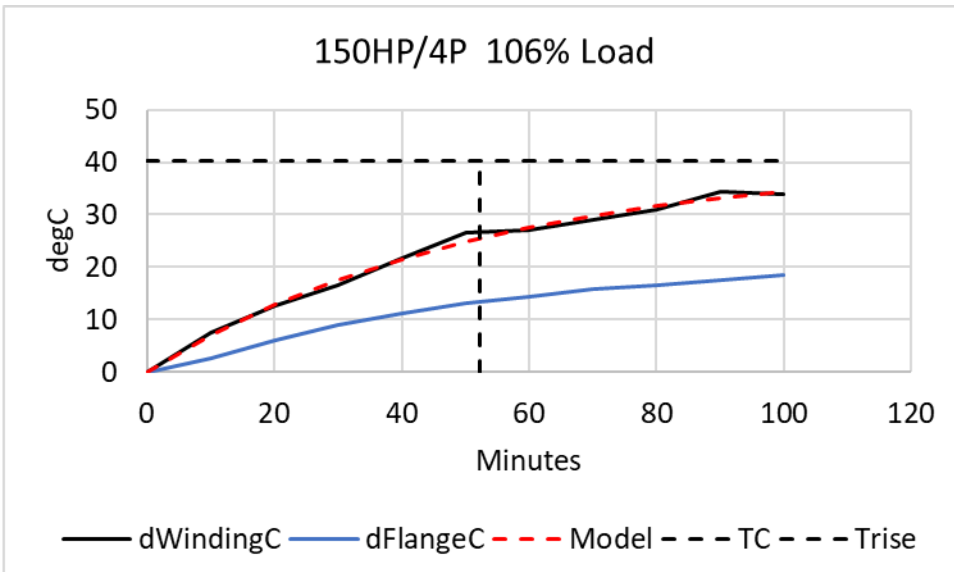


Fig 2.2, Temperature run data on 150HP/4P motor at 106% load

Temperature runs were only partially recorded for the 45HP/6P, and not at all for the 45HP/4P or 40HP/2P motors. Following is temperature data recorded on the flange only, for the 45HP/6P motor.

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| Motor | 45HP/6P | | | Minutes | R12 | R23 | R31 | Ravg | dWindingC | Flange F | Flange C | dFlangeC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | 100% | 33KW | | 0 | | | | | | 81.9 | 27.72222 | 0 |
| | | | | 10 | | | | | | 89.2 | 31.77778 | 4.055556 |
| | | | | 20 | | | | | | 97.6 | 36.44444 | 8.722222 |
| T = Tr(1-exp(-t/TC)) | | | | 30 | | | | | | 110.4 | 43.55556 | 15.83333 |
| Tr | 90.91794 | degC | | 40 | | | | | | 121.5 | 49.72222 | 22 |
| TC | 142.1412 | min | | 50 | | | | | | 131.6 | 55.33333 | 27.61111 |
| Sumsq Err | 4.561871 | | | 60 | | | | | | 139.7 | 59.83333 | 32.11111 |
| | | | | 70 | | | | | | 147.3 | 64.05556 | 36.33333 |
| | | | | 80 | | | | | | 152.9 | 67.16667 | 39.44444 |
| | | | | 90 | | | | | | 159.3 | 70.72222 | 43 |
| | | | | 100 | | | | | | 165.4 | 74.11111 | 46.38889 |
| | | | | 110 | | | | | | 171.5 | 77.5 | 49.77778 |
| | | | | 120 | | | | | | 175.5 | 79.72222 | 52 |
| | | | | 130 | | | | | | 179.6 | 82 | 54.27778 |
| | | | | 140 | | | | | | 183.4 | 84.11111 | 56.38889 |
| | | | | 150 | | | | | | 188.6 | 87 | 59.27778 |
| | | | | 160 | | | | | | 191.7 | 88.72222 | 61 |
| | | | | 170 | | | | | | 195.5 | 90.83333 | 63.11111 |

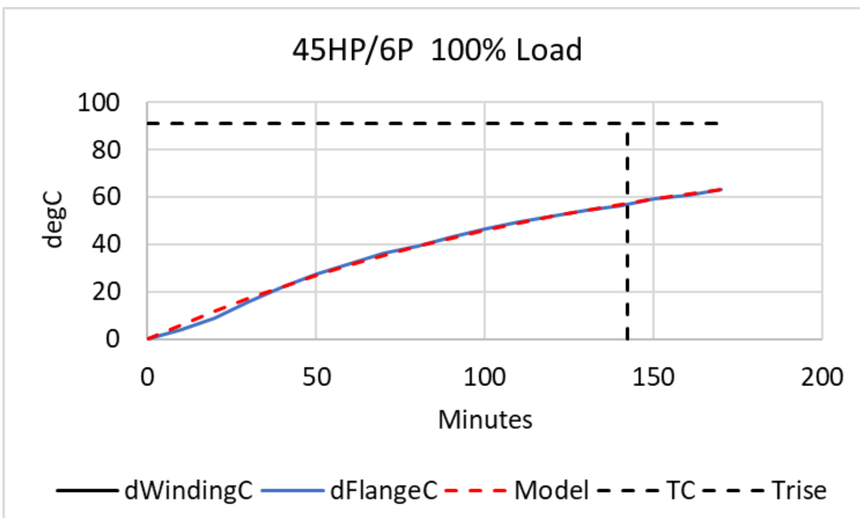


Fig 2.3, Temperature run data from cooling fin on 45HP/6P motor at ~100% load

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### 3. Locked Rotor Performance, Single Phase Tests

A single phase simulated locked rotor test is described in Part 7.2.1 of IEEE-112 [2] as an alternative to physically locking the rotor. In this test, at least three steps of reduced voltages (typ 20-60% of rated V) are briefly applied across any two terminals (e.g. V12, V23, or V31). The voltage, current and power are recorded, graphed vs voltage as in Fig 4.1 below, and extrapolated to results at rated voltage. The exponent (slope from the log-log fit) obtained from this test is a unique characteristic of the motor design, and is used to extrapolate results obtained at one test voltage, to expected results at rated voltage. Typically, the exponent for locked-rotor Current-vs-voltage is between 1.0 and 1.2, and for LR Torque double that, between 2.0 and 2.4.

This test was performed on all 5 motors, with the results as follows. The lines labeled “torque ratio” are simply an indication of the relative output of the 5 motors.

| | 40HP/2P | 45HP/4P | 45HP/6P | 150HP/4P | 175HP/8P | Comment |
|---|---|---|---|---|---|---|
| **Nameplate Data** **Model** | IE-200L-2 | IE-225S-4 | IE-250M-6 | IE-315S-4 | IE-355M1-8 | |
| Rated Volts | 480 | 480 | 480 | 480 | 480 | |
| Rated Amps | 40.2 | 49 | 49.4 | 139 | 167 | |
| Rated RPM | 3588 | 1788 | 1188 | 1792 | 891 | |
| Rated HP | 40 | 45 | 45 | 148 | 177 | |
| PF | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | |
| Poles | 2 | 4 | 6 | 4 | 8 | |
| Rated Torque, Nm | 79 | 179 | 269 | 588 | 1413 | |
| Efficiency | 95.1 | 94.0 | 95.6 | 97.4 | 96.1 | From motor drawing |
| Expected torque ratio | 1 | 2.25 | 3.38 | 7.40 | 17.7 | From HP, poles |
| Nameplate torque ratio | 1 | 2.26 | 3.40 | 7.41 | 17.8 | |
| Inertia test dia, mm | 80 | 60 | 65 | 204 | 204 | |
| Starting Current ratio | 7.6 | 9.6 | 7.1 | 7.0 | 6.8 | From motor drawing |
| Starting Torque Ratio | 3.3 | 2.5 | 2.1 | 2.2 | 2.0 | From motor drawing |
| **Single Phase Exponent Test Results** | | | | | | |
| Amps Exponent | 1.017 | 1.063 | 1.031 | 1.020 | 1.025 | Check: slightly >1 |
| Watts Exponent | 2.029 | 2.114 | 2.053 | 2.043 | 2.025 | Check: >2 |
| Ratio (Watts exp / Amps exp) | 1.995 | 1.990 | 1.990 | 2.004 | 1.975 | Check: Should be 2 |
| LR Watts @ Rated V (extrapolated) | 105,061 | 100,073 | 162,643 | 296,755 | 329,454 | |
| LR Air Gap Torque @ Rated V, Nm | 177.6 | 314.6 | 736.1 | 1109.7 | 2789.7 | |
| LRT / Rated Torque | 2.24 | 1.76 | 2.73 | 1.89 | 1.97 | |
| LR Amps @ rated V (extrapolated) | 373 | 350 | 456 | 1140 | 991 | |
| LRA / Rated Amps | 9.27 | 7.15 | 9.24 | 8.20 | 5.93 | |
| | | | | | | |
| **Static Test Results** | | | | | | |
| LL Phase Resistance | 0.1373 | 0.1660 | 0.1683 | 0.0337 | 0.0339 | |

Table 3.1, Single Phase Locked Rotor Test Results

## 4. Locked Rotor Performance

The following table shows locked rotor tests from multiple tests, including the Adventech datasheets and Advanced Energy test results for comparison.

| **Comparison of Locked Rotor Values** | 40HP/2P | 45HP/4P | 45HP/6P | 150HP/4P | 175HP/8P |
|---|---|---|---|---|---|
| LRA Adventech Datasheet | 7.6 | 9.6 | 7.1 | 7.00 | 6.80 |
| LRA Advanced Energy | 10.5 | 8.1 | 10.4 | --- | --- |
| LRA MDS Single Phase Test | 9.3 | 7.2 | 9.2 | 8.2 | 5.9 |
| LRA MDS Start Tests | 8.9 | 6.5 | 9.3 | 6.5 | 6.1 |
| LRT Adventech Datasheet | 3.3 | 2.5 | 2.1 | 2.2 | 2.0 |
| LRT Advanced Energy | 3.1 | 2.5 | 3.5 | --- | --- |
| LRT MDS Single Phase Test | 2.2 | 1.8 | 2.7 | 1.9 | 2.0 |
| LRT MDS Start Tests | 2.4 | 2.2 | 3.5 | 2.1 | 2.0 |

Table 4.1 Locked Rotor Values

### 5. Data at Rated Load on Dynamometer

Not all of the motors were tested on the dynamometer during MDS visit. Detailed data was acquired only on the 150HP/4P and 175HP/8P.

**150HP/4Pole,** from "*Rated_Load_150HP_4P_IE-315S-4_1000078_ADV_2021_166110835.csv*"

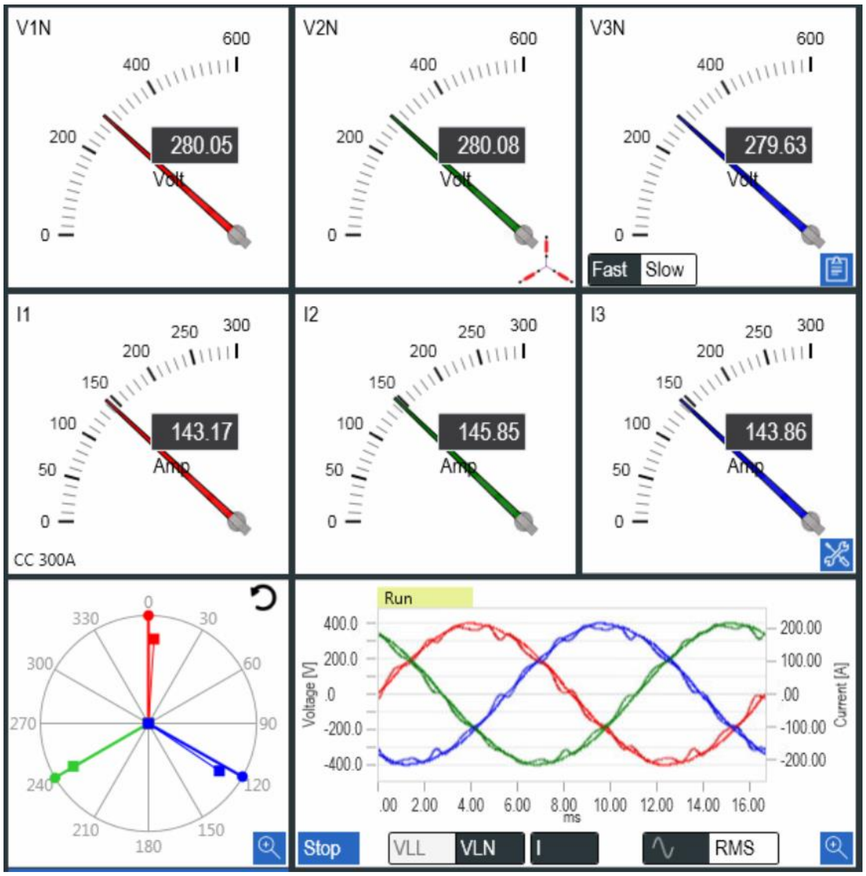


Fig. 6.1 Voltage & Current on 150HP/4P motor while rated load was indicated on the Adventech dynamometer. Note the ~unity power factor as indicated by ~zero phase lag between voltage and current. (Voltage meters showing VLN, not VLL)

MDS
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Dynamic-MotorAnalyzer

15/06/2021 11:10:03 X

Manufacturer : Adventech
Model number : IE-315S-4
Serial number : 1000078_ADV

**Voltage**

| | | Fundamental | Total | max | min | CF | THD | HVF |
|---|---|---|---|---|---|---|---|---|
| V1N | Vrms | 280.0 | 280.0 | 280.1 | 279.5 | 1.43 | 1.43 | 0.01 |
| V2N | Vrms | 280.0 | 280.0 | 280.1 | 279.6 | 1.43 | 1.22 | 0.01 |
| V3N | Vrms | 279.5 | 279.5 | 279.7 | 279.2 | 1.43 | 1.28 | 0.01 |
| VLNavg | Vrms | 279.8 | 279.9 | | | | | |
| VLN≠ unbalance | % | 0.11 | 0.11 | | | | | |
| f | Hz | | 60.04 | 60.05 | 60.00 | | | |
| Angle V1N↔V2N | ° | | 120.3 | | | | | |
| Angle V2N↔V3N | ° | | 120.1 | | | | | |
| Angle V3N↔V1N | ° | | 119.6 | | | | | |
| cosφ V1N↔I1 | | | 1.00 | | | | | |
| cosφ V2N↔I2 | | | 1.00 | | | | | |
| cosφ V3N↔I3 | | | 1.00 | | | | | |
| V12 | Vrms | 485.6 | 485.6 | 485.9 | 484.3 | | | |
| V23 | Vrms | 484.8 | 484.9 | 485.4 | 483.8 | | | |
| V31 | Vrms | 483.6 | 483.6 | 484.1 | 482.6 | | | |
| VLLavg | Vrms | 484.7 | 484.7 | | | | | |
| V% of Vrated | % | 101.0 | 101.0 | | | | | |
| VLL≠ unbalance | % | 0.22 | 0.22 | | | | | |
| Nema derating | % | 100.0 | | | | | | 100.0 |

**Current**

| | | Fundamental | Total | max | min | CF | THD |
|---|---|---|---|---|---|---|---|
| I1 | Arms | 144.27 | 144.61 | 146.40 | 143.36 | 1.45 | 6.37 |
| I2 | Arms | 147.09 | 147.27 | 149.20 | 146.23 | 1.44 | 4.35 |
| I3 | Arms | 144.89 | 145.16 | 146.67 | 143.75 | 1.45 | 5.54 |
| Iavg | Arms | 145.42 | 145.68 | | | | |
| I≠ unbalance | % | 1.15 | 1.09 | | | | |
| I% of Irated | % | 104.62 | 104.81 | | | | |

Start measurement

**Electric Power**

| | | | phase 1 | phase 2 | phase 3 | Total | ≠Unbal.% |
|---|---|---|---|---|---|---|---|
| P | Active power | KW | 40.36 | 41.11 | 40.48 | 121.95 | 1.14 |
| S | Apparent power | KVA | 40.50 | 41.24 | 40.58 | 122.31 | 1.14 |
| Q | Reactive power | KVAR | 3.29 | 3.15 | 2.85 | 9.30 | 8.05 |
| PF | Power Factor | | 1.00 | 1.00 | 1.00 | 1.00 | |

**Impedance**

| | | Phase 1-2 | Phase 2-3 | Phase 3-1 | ≠Unbal.% |
|---|---|---|---|---|---|
| Z | Ω | 1.94 | 1.90 | 1.93 | 1.04 |
| Real | Ω | 1.93 | 1.90 | 1.92 | 1.04 |
| Imaginary | Ω | 0.16 | 0.15 | 0.14 | 7.82 |

**Motor**

| | | | Rated | Conv. | DQ | M,n-sensor |
|---|---|---|---|---|---|---|
| Prated | Rated power | HP | 147.5 | | | |
| p | Pole number | | 4 | | | |
| nrated | Rated speed | Rpm | 1792 | | | |
| Mrated | Rated torque | lbf ft | 432.3 | | | |
| ηrated | Rated efficiency | % | 96.15 | | | |
| Pscl | stator copper losses | HP | | 1.9 | | |
| Pair | Air-gap power | HP | | 161.6 | | |
| Prcl | rotor copper losses | HP | | | | |
| Pfe | iron losses | VAR | | | | |
| Pstray | stray losses | VAR | | | | |
| nsynch | Synchronous speed | Rpm | | 1801.8 | 1800.7 | 1801.8 |
| n | speed | Rpm | | n/a | 1788.7 | n/a |
| s | Slip | | | n/a | 0.007 | n/a |
| Pmech | estimated power | HP | | 161.57 | 160.47 | n/a |
| P% | estimated % of Prated | % | | 109.6 | 108.8 | |
| Mmech | torque | lbf ft | | n/a | 471.38 | n/a |
| Mripple | estimated torque ripple | lbf ft | | | 77.3 | |
| η | estimated efficiency | % | | 98.84 | 98.16 | n/a |

n/a = value is incalculateable because of missing setting values or measurement results.

Fig 6.2 Summary of readings from 150HP/4P motor while rated load was indicated on Adventech dynamometer. Note the unity power factor, to the resolution of this display.

MOTOR DIAGNOSTIC SYSTEMS

**177HP/8P,** from "*Full_Load_177HP_8P_IE-355M1-8_1000141ADV_2021_166170107.csv*"

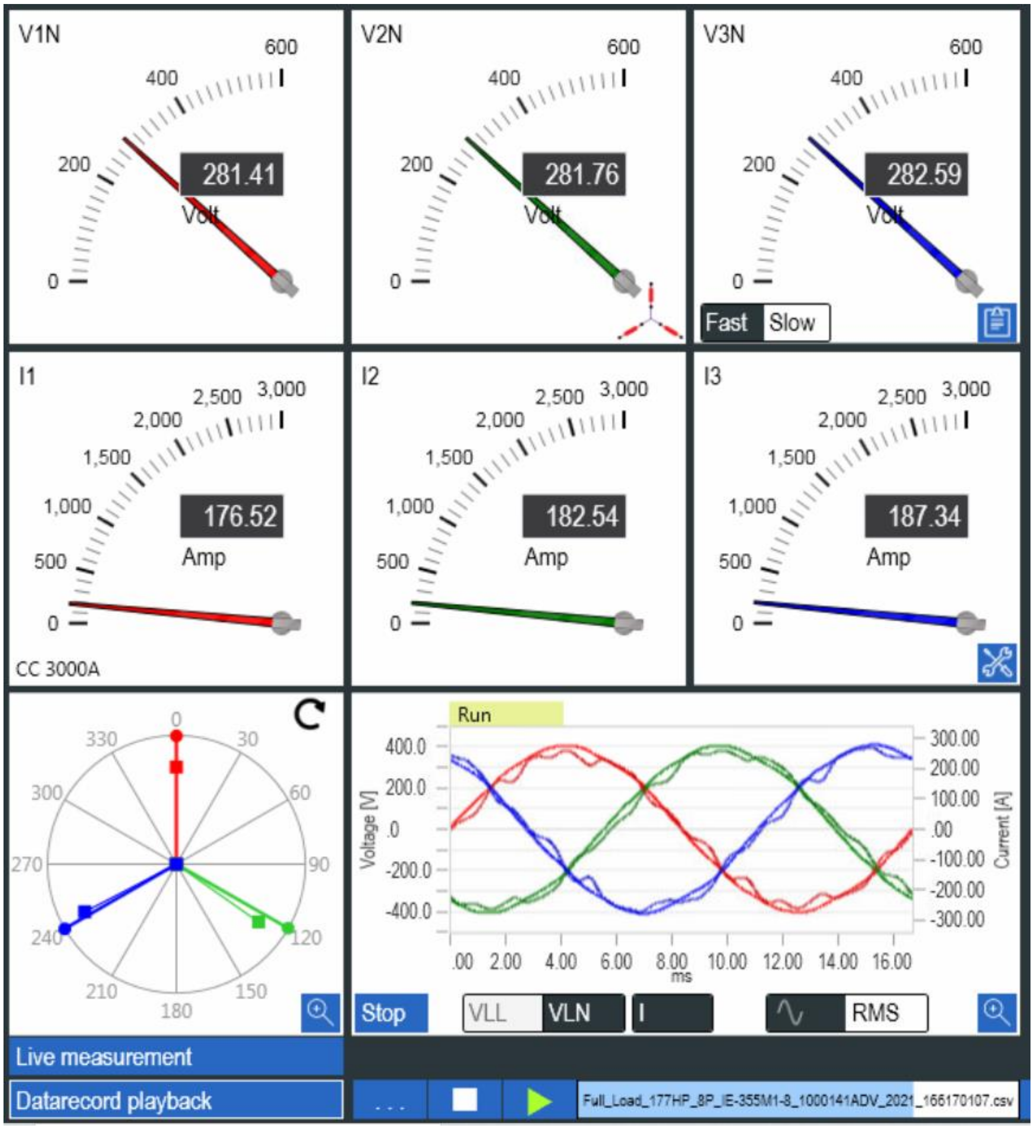
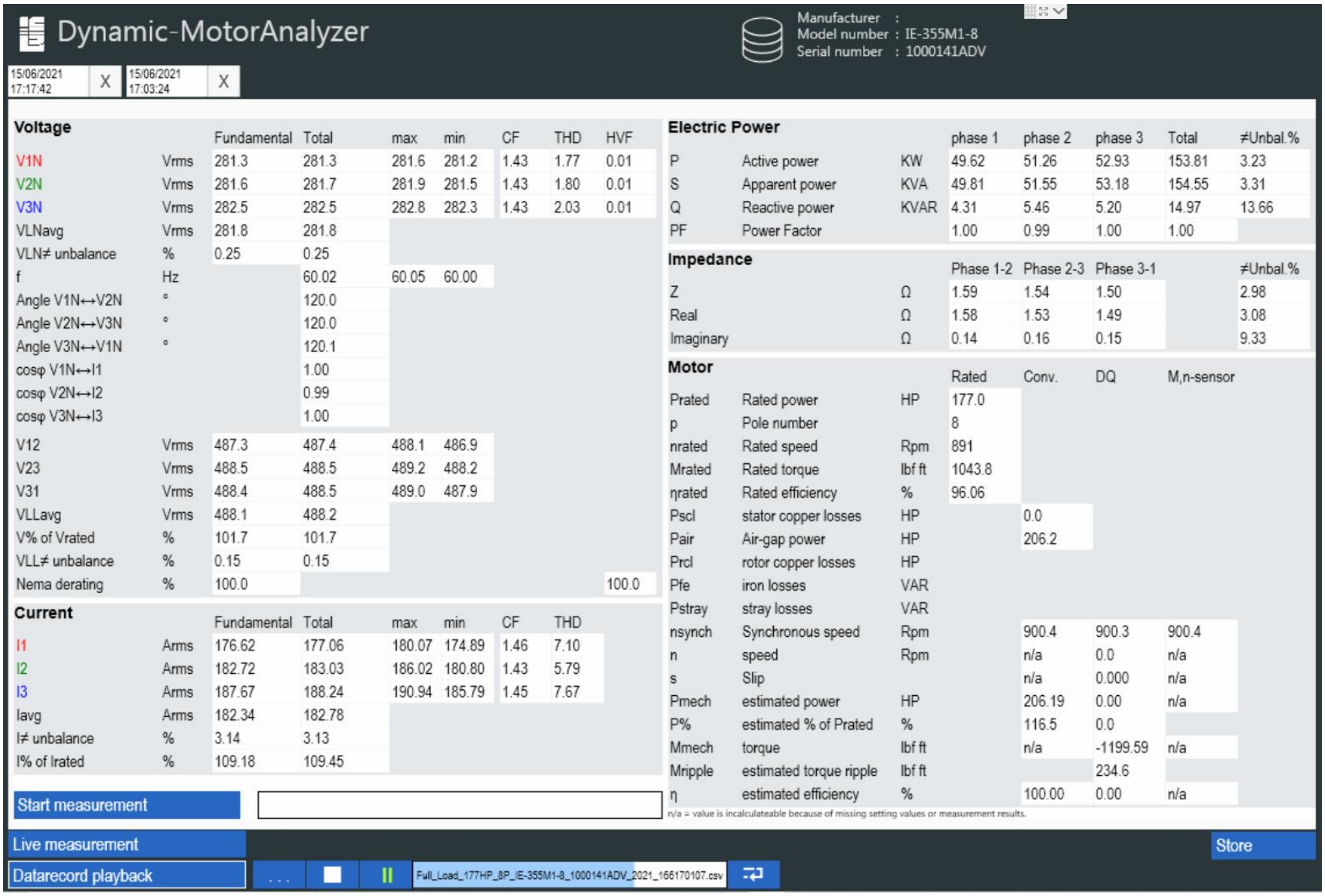



Fig. 6.3, Display from 175HP/8P motor while indicating rated load on dynamometer. Note near-unity power factor as indicated by coincidence of voltage and current waveforms. (VLN shown on voltage meters, not VLL)

MOTOR DIAGNOSTIC SYSTEMS



Dynamic-MotorAnalyzer

15/06/2021 17:17:42 X | 15/06/2021 17:03:24 X

Manufacturer :
Model number : IE-355M1-8
Serial number : 1000141ADV

| Voltage | | Fundamental | Total | max | min | CF | THD | HVF |
|---|---|---|---|---|---|---|---|---|
| V1N | Vrms | 281.3 | 281.3 | 281.6 | 281.2 | 1.43 | 1.77 | 0.01 |
| V2N | Vrms | 281.6 | 281.7 | 281.9 | 281.5 | 1.43 | 1.80 | 0.01 |
| V3N | Vrms | 282.5 | 282.5 | 282.8 | 282.3 | 1.43 | 2.03 | 0.01 |
| VLNavg | Vrms | 281.8 | 281.8 | | | | | |
| VLN≠ unbalance | % | 0.25 | 0.25 | | | | | |
| f | Hz | | 60.02 | 60.05 | 60.00 | | | |
| Angle V1N↔V2N | ° | | 120.0 | | | | | |
| Angle V2N↔V3N | ° | | 120.0 | | | | | |
| Angle V3N↔V1N | ° | | 120.1 | | | | | |
| cosφ V1N↔I1 | | | 1.00 | | | | | |
| cosφ V2N↔I2 | | | 0.99 | | | | | |
| cosφ V3N↔I3 | | | 1.00 | | | | | |
| V12 | Vrms | 487.3 | 487.4 | 488.1 | 486.9 | | | |
| V23 | Vrms | 488.5 | 488.5 | 489.2 | 488.2 | | | |
| V31 | Vrms | 488.4 | 488.5 | 489.0 | 487.9 | | | |
| VLLavg | Vrms | 488.1 | 488.2 | | | | | |
| V% of Vrated | % | 101.7 | 101.7 | | | | | |
| VLL≠ unbalance | % | 0.15 | 0.15 | | | | | |
| Nema derating | % | 100.0 | | | | | | 100.0 |

| Current | | Fundamental | Total | max | min | CF | THD |
|---|---|---|---|---|---|---|---|
| I1 | Arms | 176.62 | 177.06 | 180.07 | 174.89 | 1.46 | 7.10 |
| I2 | Arms | 182.72 | 183.03 | 186.02 | 180.80 | 1.43 | 5.79 |
| I3 | Arms | 187.67 | 188.24 | 190.94 | 185.79 | 1.45 | 7.67 |
| Iavg | Arms | 182.34 | 182.78 | | | | |
| I≠ unbalance | % | 3.14 | 3.13 | | | | |
| I% of Irated | % | 109.18 | 109.45 | | | | |

| Electric Power | | | phase 1 | phase 2 | phase 3 | Total | ≠Unbal.% |
|---|---|---|---|---|---|---|---|
| P | Active power | KW | 49.62 | 51.26 | 52.93 | 153.81 | 3.23 |
| S | Apparent power | KVA | 49.81 | 51.55 | 53.18 | 154.55 | 3.31 |
| Q | Reactive power | KVAR | 4.31 | 5.46 | 5.20 | 14.97 | 13.66 |
| PF | Power Factor | | 1.00 | 0.99 | 1.00 | 1.00 | |

| Impedance | | | Phase 1-2 | Phase 2-3 | Phase 3-1 | | ≠Unbal.% |
|---|---|---|---|---|---|---|---|
| Z | | Ω | 1.59 | 1.54 | 1.50 | | 2.98 |
| Real | | Ω | 1.58 | 1.53 | 1.49 | | 3.08 |
| Imaginary | | Ω | 0.14 | 0.16 | 0.15 | | 9.33 |

| Motor | | | Rated | Conv. | DQ | M,n-sensor |
|---|---|---|---|---|---|---|
| Prated | Rated power | HP | 177.0 | | | |
| p | Pole number | | 8 | | | |
| nrated | Rated speed | Rpm | 891 | | | |
| Mrated | Rated torque | lbf ft | 1043.8 | | | |
| ηrated | Rated efficiency | % | 96.06 | | | |
| Pscl | stator copper losses | HP | | 0.0 | | |
| Pair | Air-gap power | HP | | 206.2 | | |
| Prcl | rotor copper losses | HP | | | | |
| Pfe | iron losses | VAR | | | | |
| Pstray | stray losses | VAR | | | | |
| nsynch | Synchronous speed | Rpm | | 900.4 | 900.3 | 900.4 |
| n | speed | Rpm | | n/a | 0.0 | n/a |
| s | Slip | | | n/a | 0.000 | n/a |
| Pmech | estimated power | HP | | 206.19 | 0.00 | n/a |
| P% | estimated % of Prated | % | | 116.5 | 0.0 | |
| Mmech | torque | lbf ft | | n/a | -1199.59 | n/a |
| Mripple | estimated torque ripple | lbf ft | | | 234.6 | |
| η | estimated efficiency | % | | 100.00 | 0.00 | n/a |

n/a = value is incalculateable because of missing setting values or measurement results.

Start measurement

Live measurement | Store

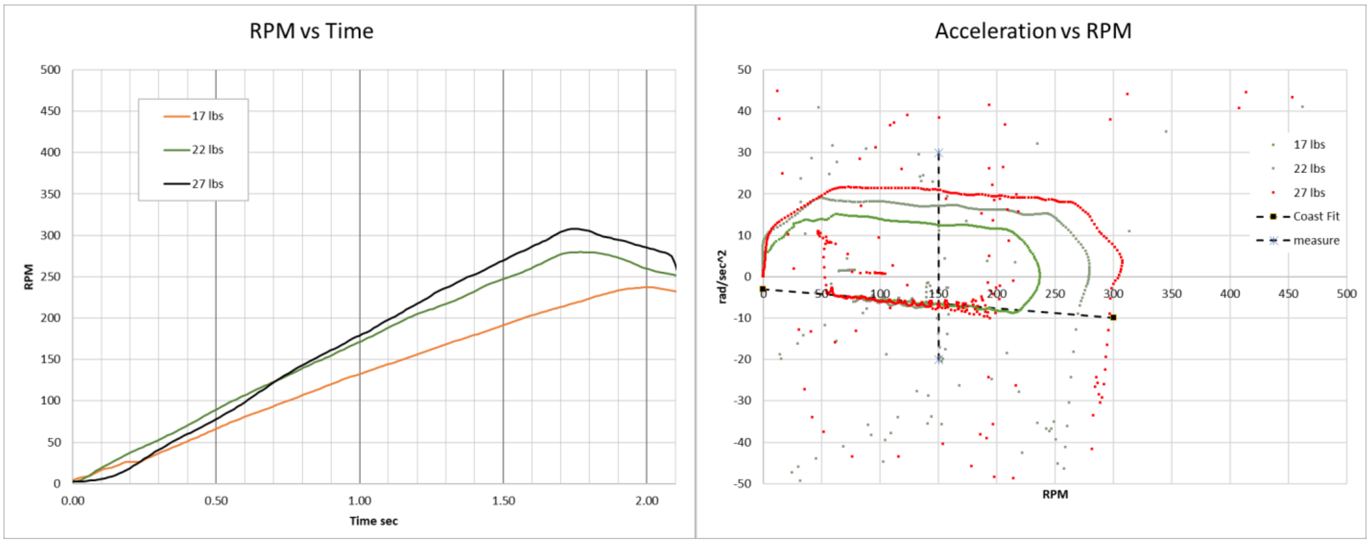
Datarecord playback | Full_Load_177HP_8P_IE-355M1-8_1000141ADV_2021_166170107.csv

Fig 6.4 Summary of readings from 175HP/8P motor while rated load was indicated on Adventech dynamometer. Note the unity power factor, to the resolution of this display.

### 6. Inertia Tests

A standalone, non-operating test of the assembled motor was performed to measure the inertia of the rotating parts. The inertia value is also derived from the motor start data, so this information is a cross check on the accuracy of the results. The measured acceleration during start is multiplied by inertia to give the mechanical output torque of the motor, vs speed. In Fig 6.1 at the right, the primary result of interest is shown. The height from the nearly-horizontal dotted baseline (coastdown) curve to the corresponding data curve, yields the acceleration provided by the test weight. This is divided into the applied torque to calculate rotor inertia, which is of course invariant.

Following are the results of inertia test on the 40HP/2P motor, where 3 trial weights were used.



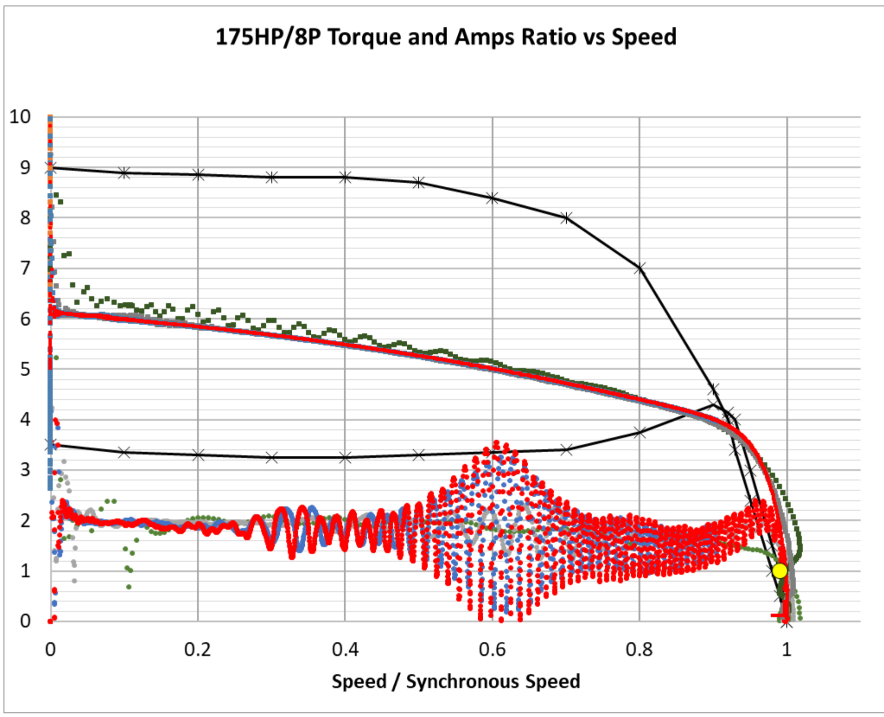

| Weight | a0@150 | af@150 | Acc | T/a = Inertia, Kg.m^2 |
|---|---|---|---|---|
| 17 lbs | -7 | 12 | 19 | 0.159482 |
| 22 lbs | -7 | 17 | 24 | 0.163333 |
| 27 lbs | -7 | 21 | 28 | 0.17178 |

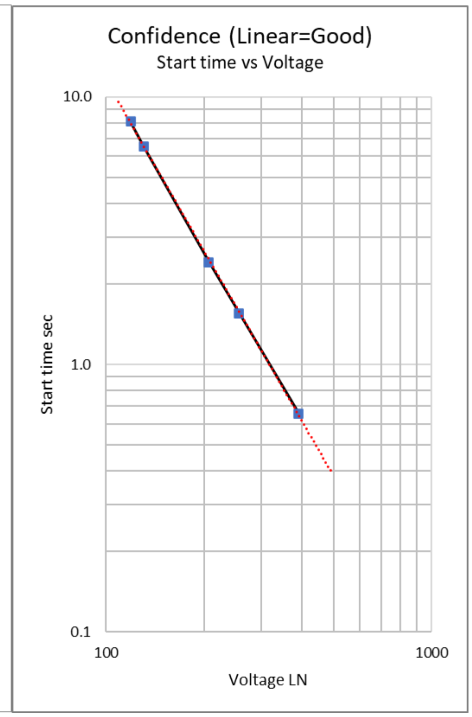
Fig. 6.1 – Non-Operating Inertia Test. Upper left, RPM vs time; upper right, acceleration vs RPM; table, numerical results from trials with 3 test weights. The test weights were weighed on an Adventech scale.

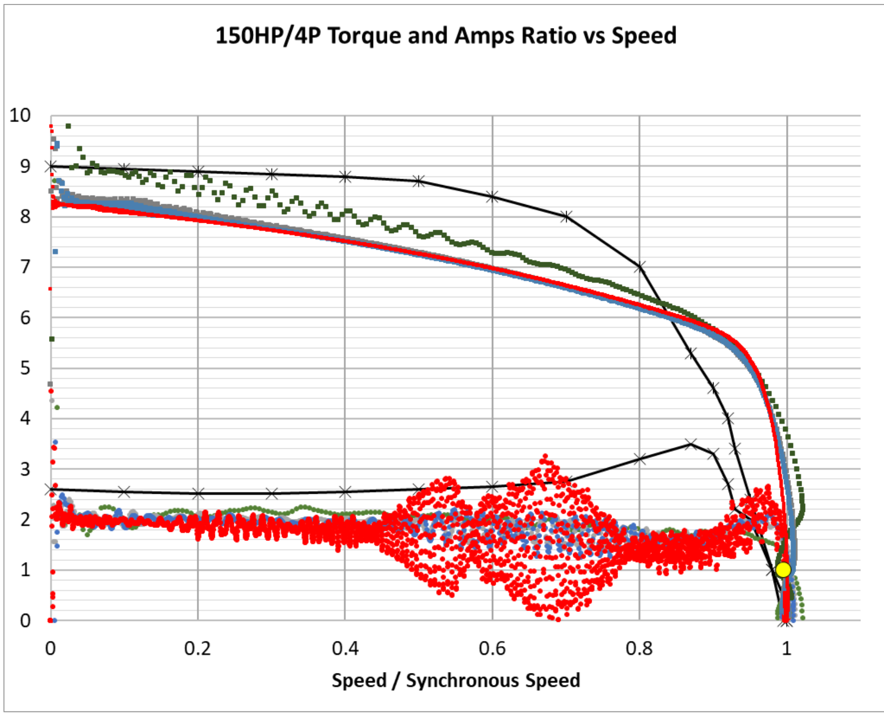
Due mainly to fixture issues, this type of inertia test was not successful on the 150HP/4P and 175HP/8P Motors.

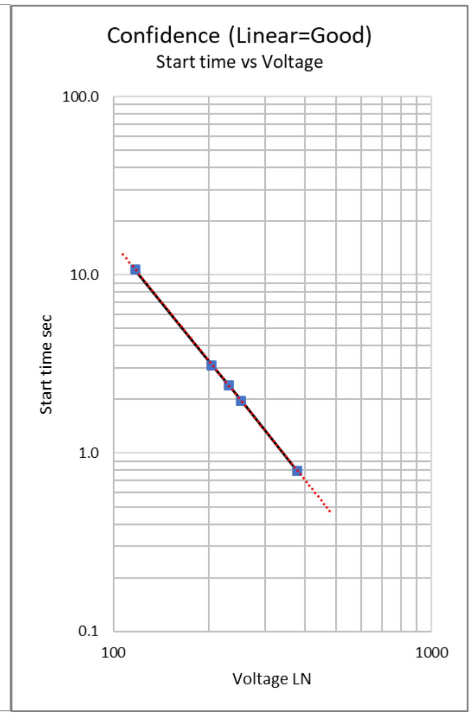
## 7. No-Load Performance Curves

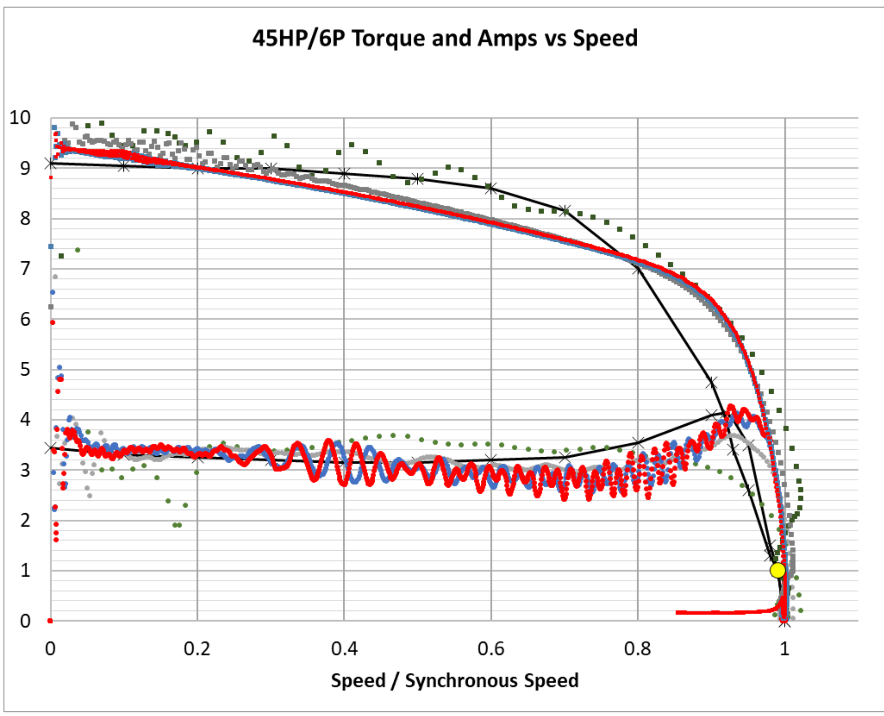
The following set of graphs present Toque and Current vs Speed obtained from across-the line starts. The Torque is acceleration multiplied by inertia, and thus is output torque. There are multiple overlapping traces as each motor was tested at 5x line voltages. The solid black lines with markers, are from Adventech datasheets. The figure to the right is a confidence line, produced by graphing start time vs line voltage. Both current and torque have been corrected to 480V using a measured voltage dependency exponent slightly >2 derived from the set of start data for each motor independently (see for example the slope of the Confidence graph).

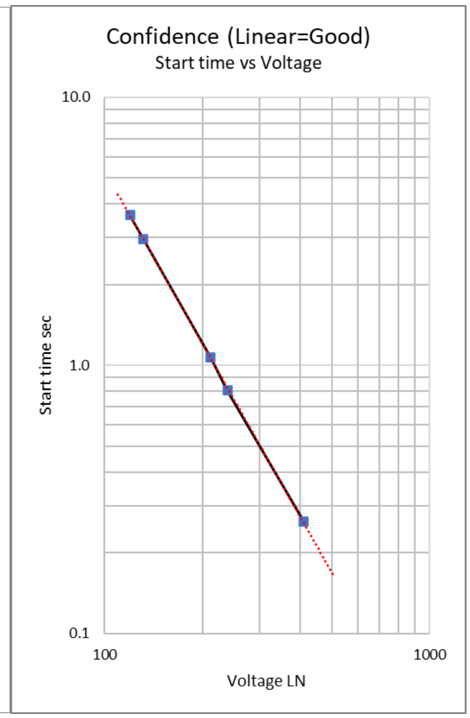


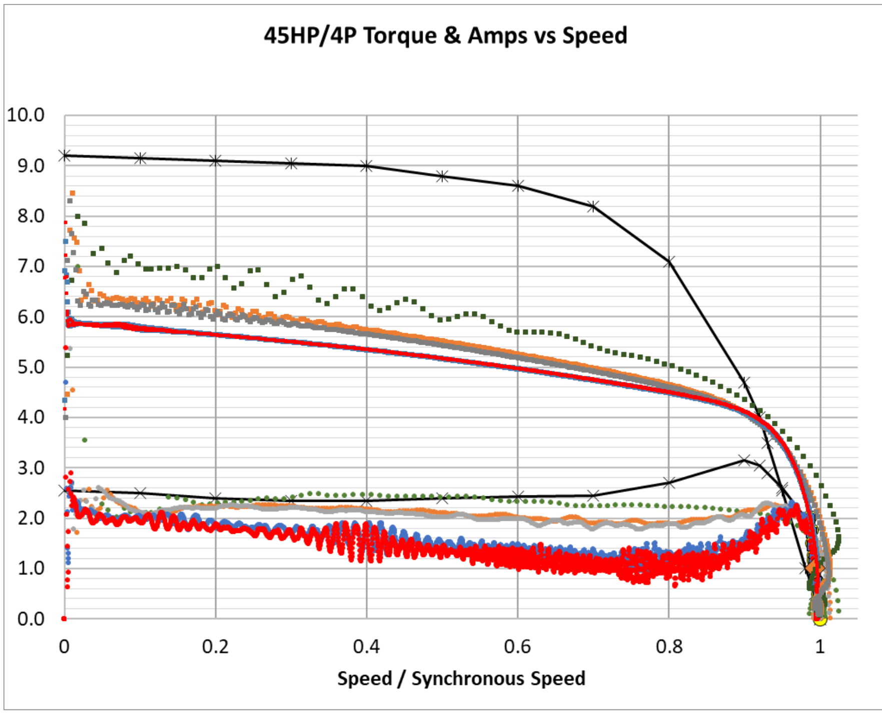



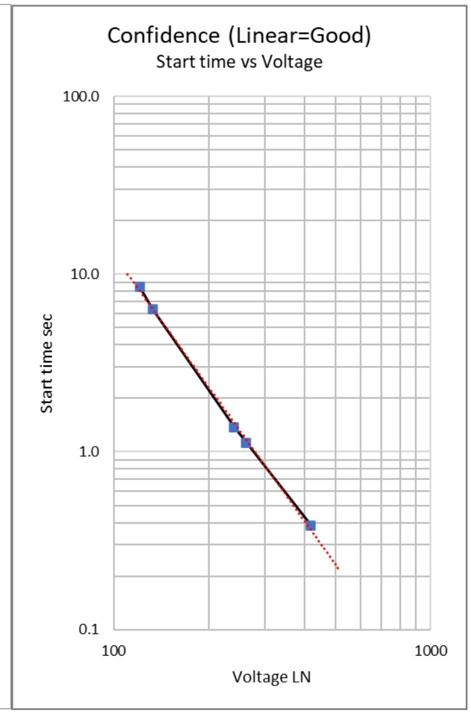

150HP/4P Torque and Amps Ratio vs Speed
Speed / Synchronous Speed

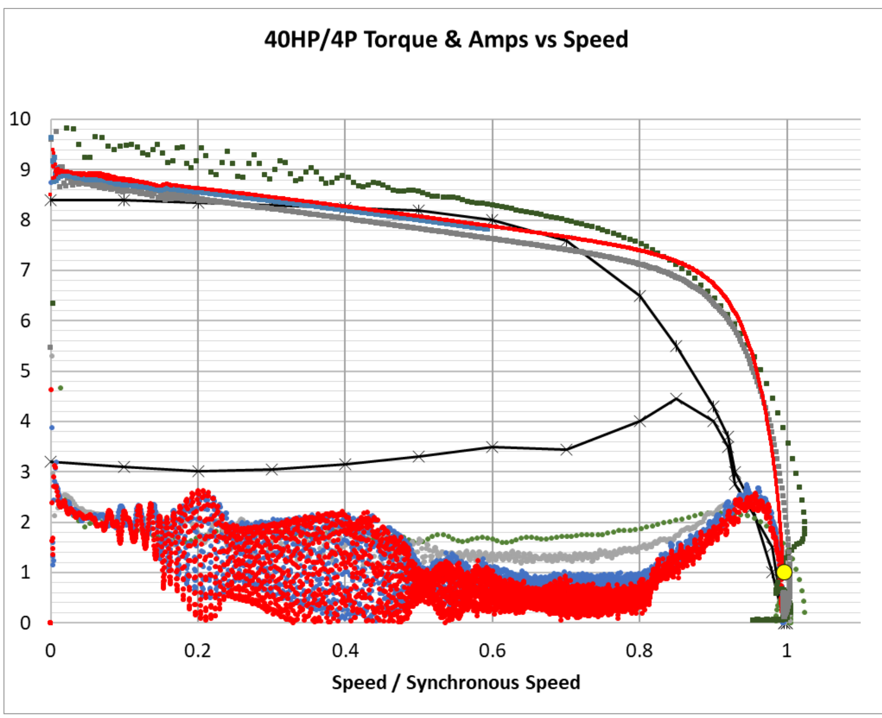

Confidence (Linear=Good)
Start time vs Voltage
Start time sec
Voltage LN

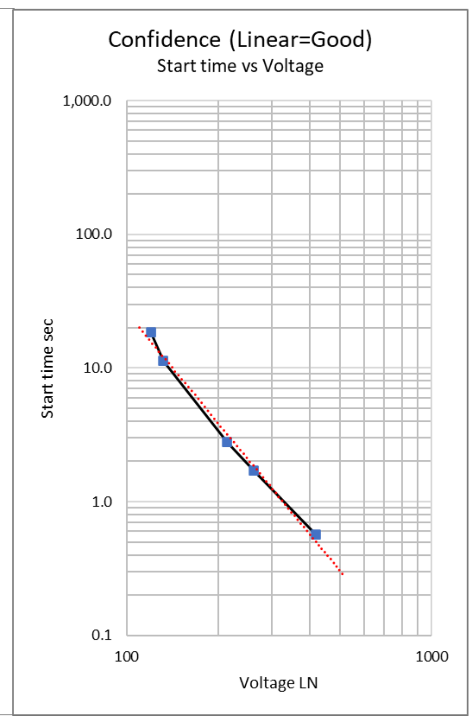

45HP/6P Torque and Amps vs Speed
Speed / Synchronous Speed


Confidence (Linear=Good)
Start time vs Voltage
Start time sec
Voltage LN

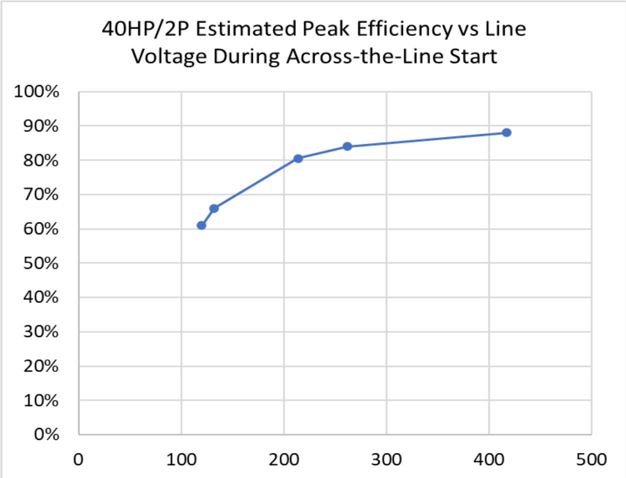

45HP/4P Torque & Amps vs Speed
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
0.2
0.4
0.6
0.8
1
Speed / Synchronous Speed

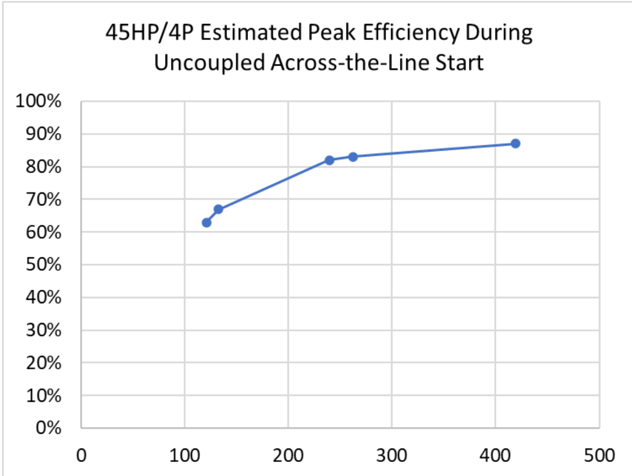

Confidence (Linear=Good)
Start time vs Voltage
100.0
10.0
1.0
0.1
Start time sec
100
1000
Voltage LN

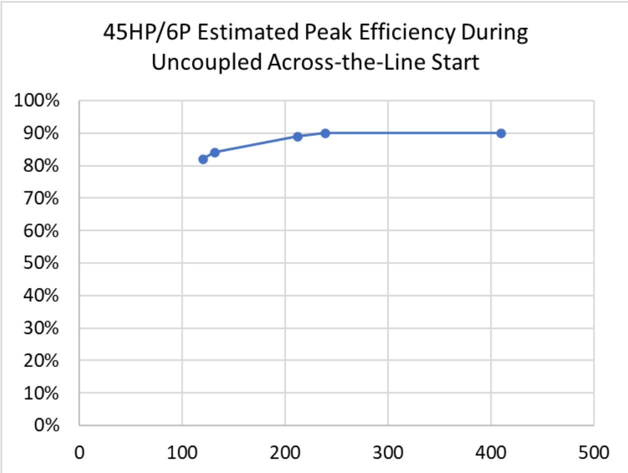

40HP/4P Torque & Amps vs Speed
10
9
8
7
6
5
4
3
2
1
0
0
0.2
0.4
0.6
0.8
1
Speed / Synchronous Speed

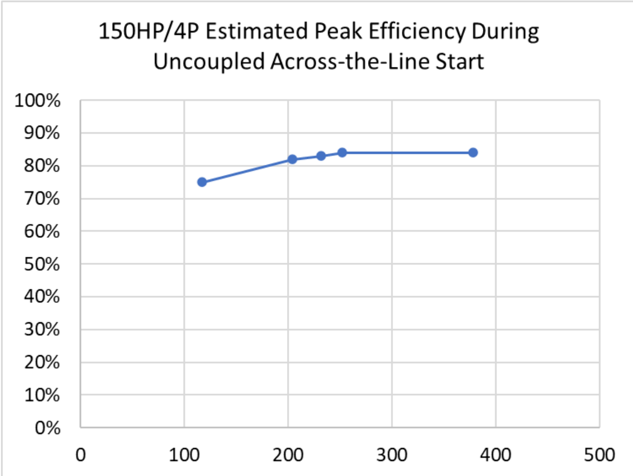

Confidence (Linear=Good)
Start time vs Voltage
1,000.0
100.0
10.0
1.0
0.1
Start time sec
100
1000
Voltage LN

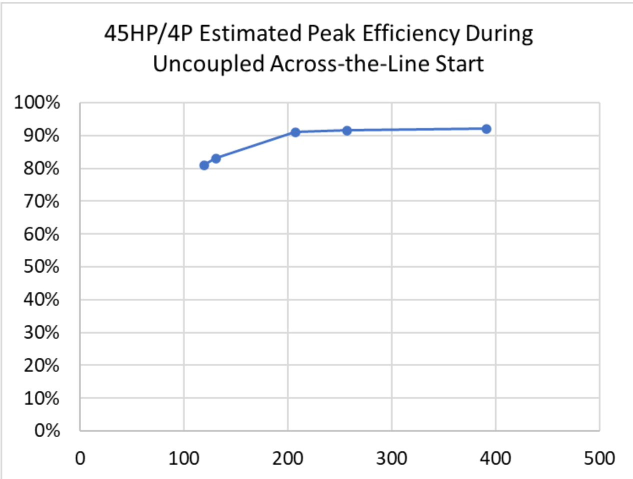
## 8. Motor Losses & Efficiency



**Notes on Dynamic Performance Curves and Efficiency**

Figure 9 below from Krause [1] illustrates the well-understood, typical behavior difference between torque measured during an uncoupled across the line start, vs steady state torque (data points at fixed speed/constant load points on a dyno), from a test of a 500HP/460V/4P induction motor.

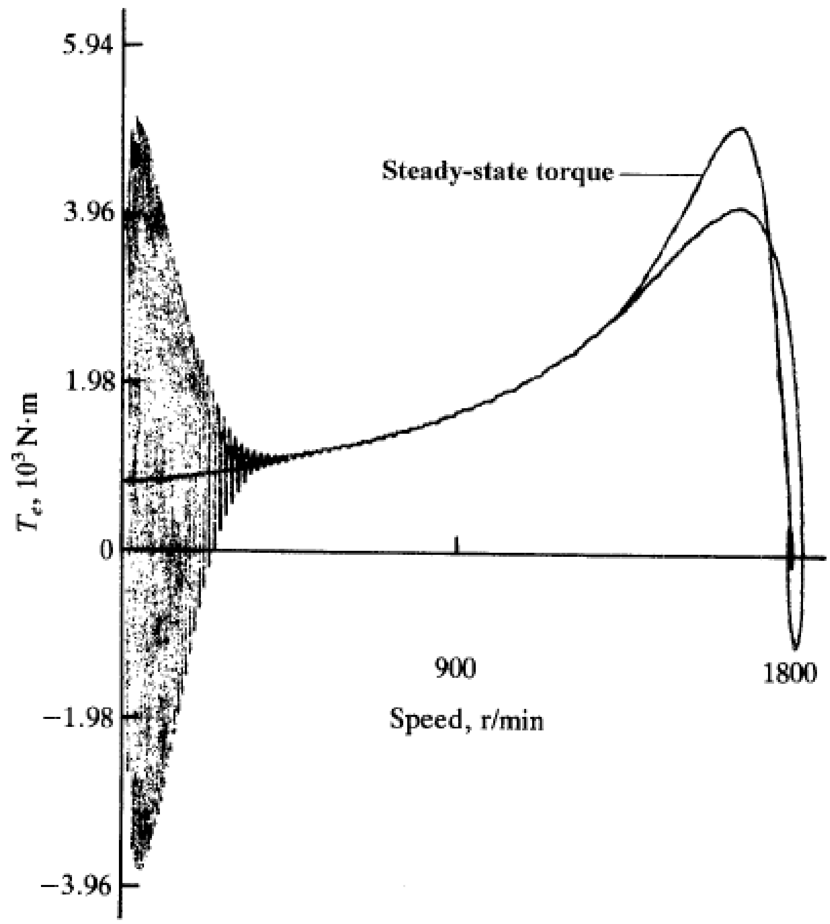



Fig 9: Steady-state vs across the line torque vs speed result, 500HP/460V/4P induction motor [1]

There are three primary areas of difference between speed-torque curves produced dynamically, vs those produced on a dyno at steady state.

1. Locked rotor torque: Immediately after power on, during an across-the-line start there is always an initial torque oscillation at line frequency (60Hz in NA) that dies out quickly. During a steady state test on a dyno, there is no oscillation at low speed unless the phase voltages or currents are unbalanced (in which case the oscillation is steady state at 2x line frequency).

2. Breakdown Torque: Because the motor is accelerating through the region where torque peaks (breakdown torque), the motor does not actually develop the full breakdown peak. The faster the acceleration (higher the line voltage), the more pronounced is the difference.
3. Full speed Overshoot: The motor speed always overshoots synchronous speed during an uncoupled across the line start, then oscillates before settling in to a steady-state no load speed. The amount of oscillation and overshoot depend on the line voltage, the effect being more pronouncecd as line voltage increases. In Fig 2 above, the overshoot and oscillation shown are about what's expected during a full-voltage start. For this reason, dynamic speed torque curves always over-estimate the steady-state results, with the difference increasing with line voltage.

## References


1. Paul Krause, Oleg Wasynczuk, Scott D. Sudhoff - *Analysis of Electric Machinery and Drive Systems*, 2nd Edition, Wiley/IEEE Press 2002, ISBN-13: 978-0471143260, ISBN-10: 047114326X
2. IEEE 112-2017, *IEEE Standard Test Procedure for Polyphase Induction Motors and Generators*, Pub 2018-02-14
3. *Final Observations and Comments from Adventech Motor Tests June 2021*, MDS, Inc., July 2021