Synopsis

A series of tests has been done to try to isolate the cause of the motor failures during the June 2009 FOCE deployment, in which the motors would stop running after 10-20 seconds, when commanded to speeds between ~50-340 counts/sec (8-50 RPM shaft speed).

Procedure

Two sets of tests were performed. The first was a series of qualitative tests (quick and easy to perform) that indicate where to look for possible mechanical components to the problem by showing the relative proportions of the power consumed by various system components.

In these tests, the FOCE motor test fixture was used to test the FOCE motors in several configurations:

- motor w/ drive train [in ~10C air]
- motor w/ drive train [in ~4C water]
- motor w/o drive train
- motor w/o drive train w/o oil

Each configuration was run at two speeds (150 and 300 counts/sec) to cover a large portion of our operation space with a 2x change in velocity.

A comparison of these configurations isolates the contribution of the water loading, the drive train loading and the loading of the oil.

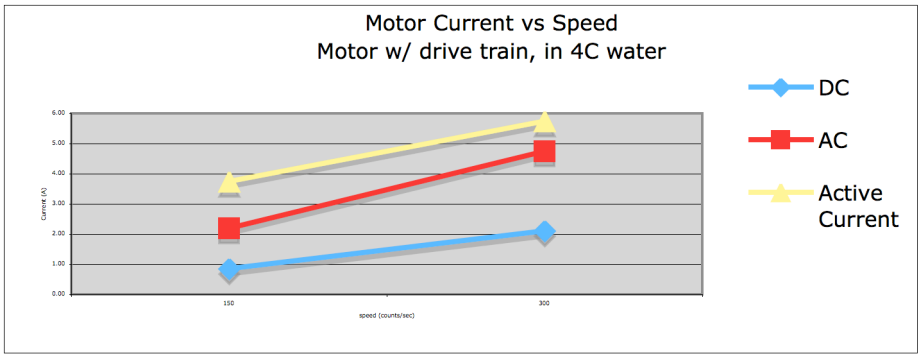
For each scenario, the step response of the system was recorded using Elmo Scope, and the steady state power supply current was recorded using a DVM in both AC and DC modes. The Elmo Scope application records the startup and steady state waveforms for motor currents, velocity and Elmo DC bus voltage. None of the measurements of current are an exact RMS representation, since the DVM is a filtered average of a PWM waveform, and the Elmo Scope application shows Active Current (the torque producing current component) and the sinusoidal phase currents. However, a side by side comparison indicates that they are reasonably proportional, and so any of these provides a reasonable basis for comparing the relative power consumption of each configuration.

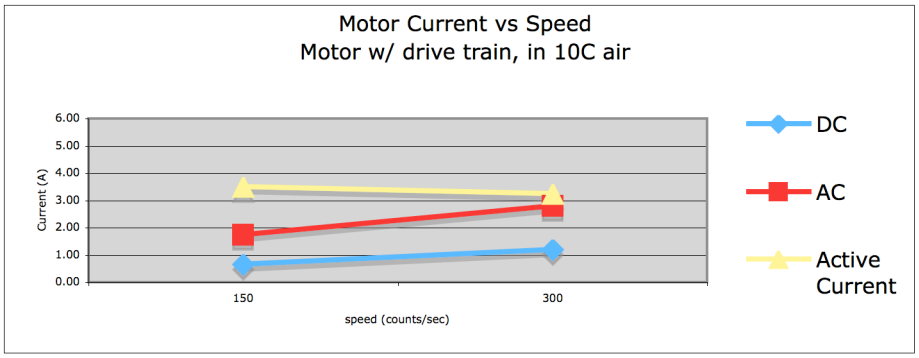
In the second set of tests, a current probe was used to quantitatively measure the current and voltage waveforms during over-current events that cause the Elmo drive to reset. These events are not visible through the Elmo Composer software suite, because it requires continuous communication with the drive to function properly. These tests reveal any electrical components to the problem. The qualitative power isolation tests were repeated to provide a better sense of potential drive train optimizations.

Analysis

Qualitative Tests

The first two plots (see Data Section) show motor current vs speed, measured in terms of AC and DC currents measured with a DVM, as well as the approximate steady state Active current reported by Elmo Scope. The graphs show that while these are different, they are essentially proportional, and so any should be valid for comparing (qualitatively but proportionally) the power used by different configurations.





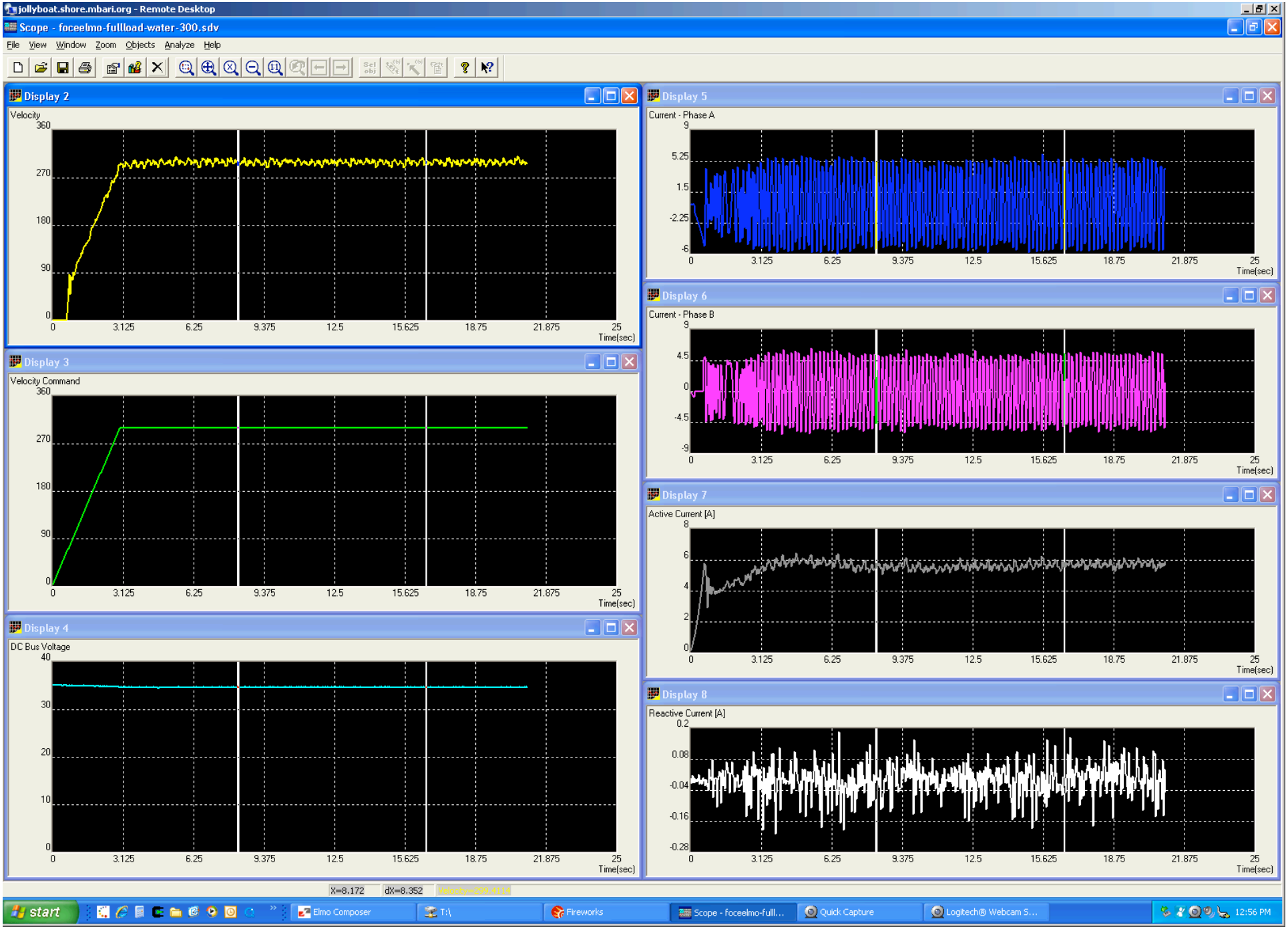
In water, the *difference* in current (not absolute current) required to double the speed is greater than in air by a factor of about 4.

The next two plots (see Data Section) show current consumption vs configuration, each at a different speed (left to right):

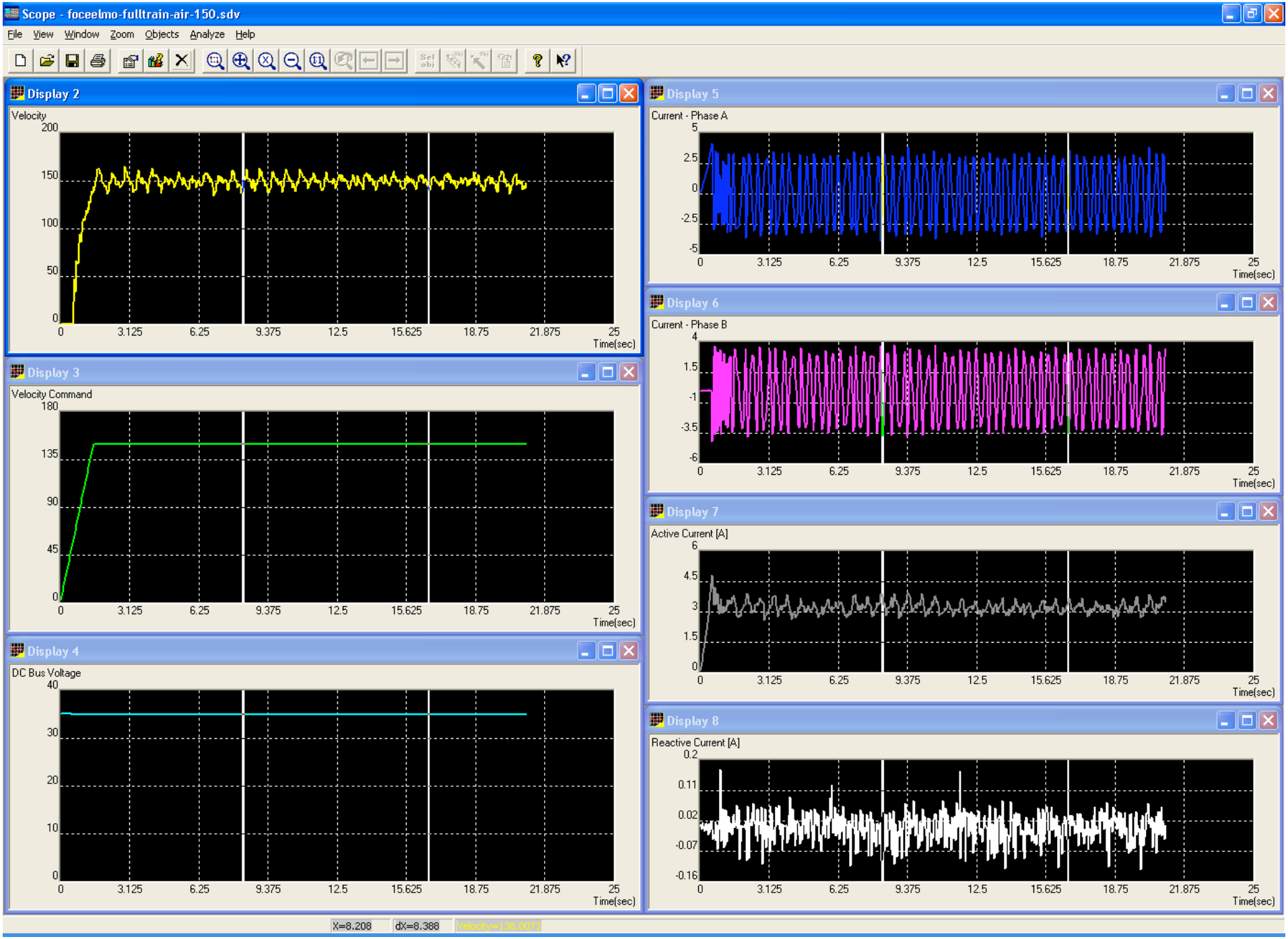
- motor w/o drive train or oil
- motor w/o drive train (w/ oil)
- motor w/drive train (in air)
- motor w/ drive train (in water).

There is a significant difference in the amount of current drawn between the cases with and without the drive train. The difference between the cases in air and water are larger at the higher speed (by factor of about 4).

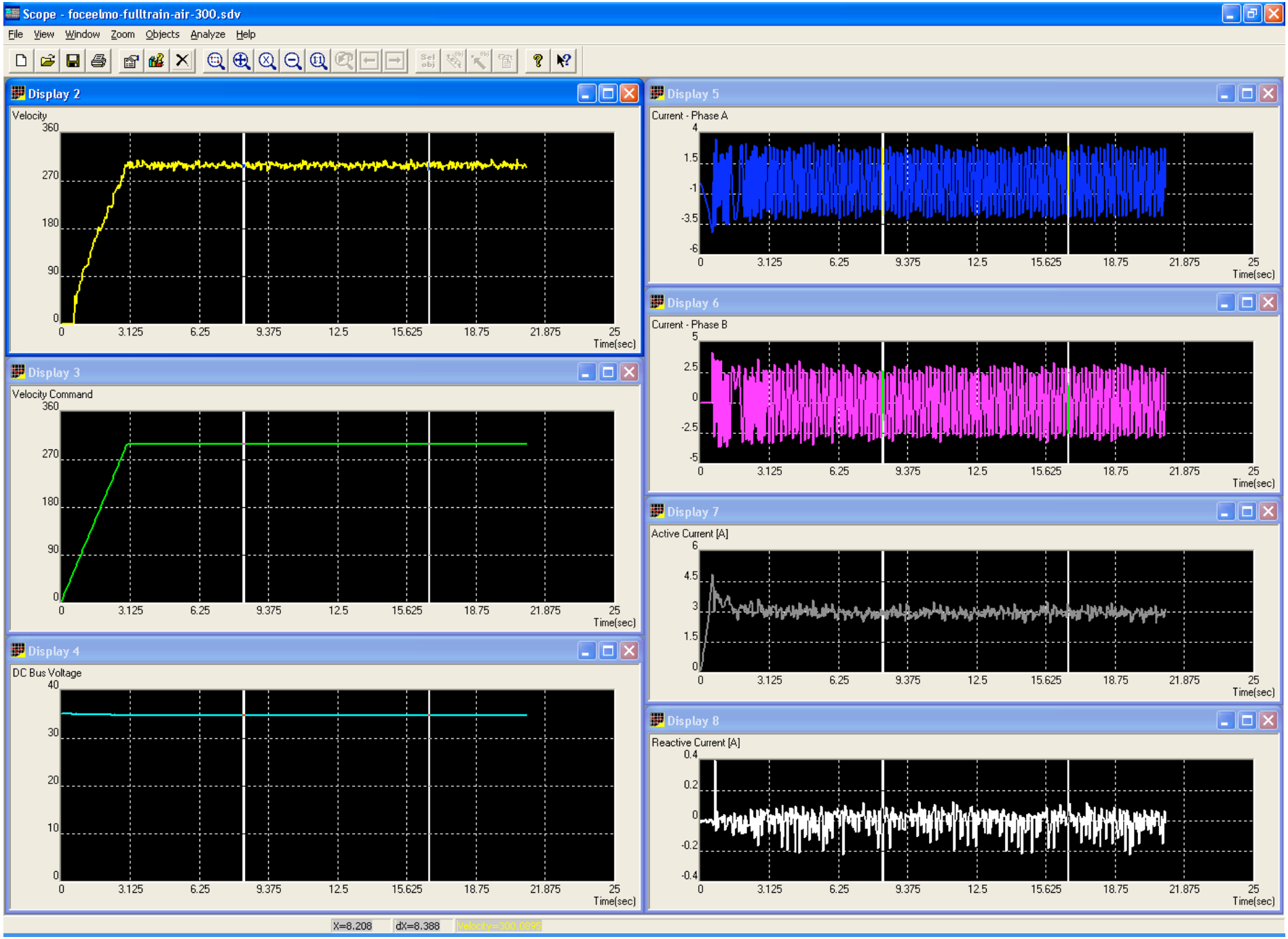
The active current (see Elmo Scope output below) can go above the current limit set for the DC power supply; this may be because the Elmo PWM scheme may be effectively lowering voltage to increase apparent current to the drive to produce the required torque. We need to repeat the measurements with a current probe and voltage measurement to capture the exact behavior at the power supply terminals.



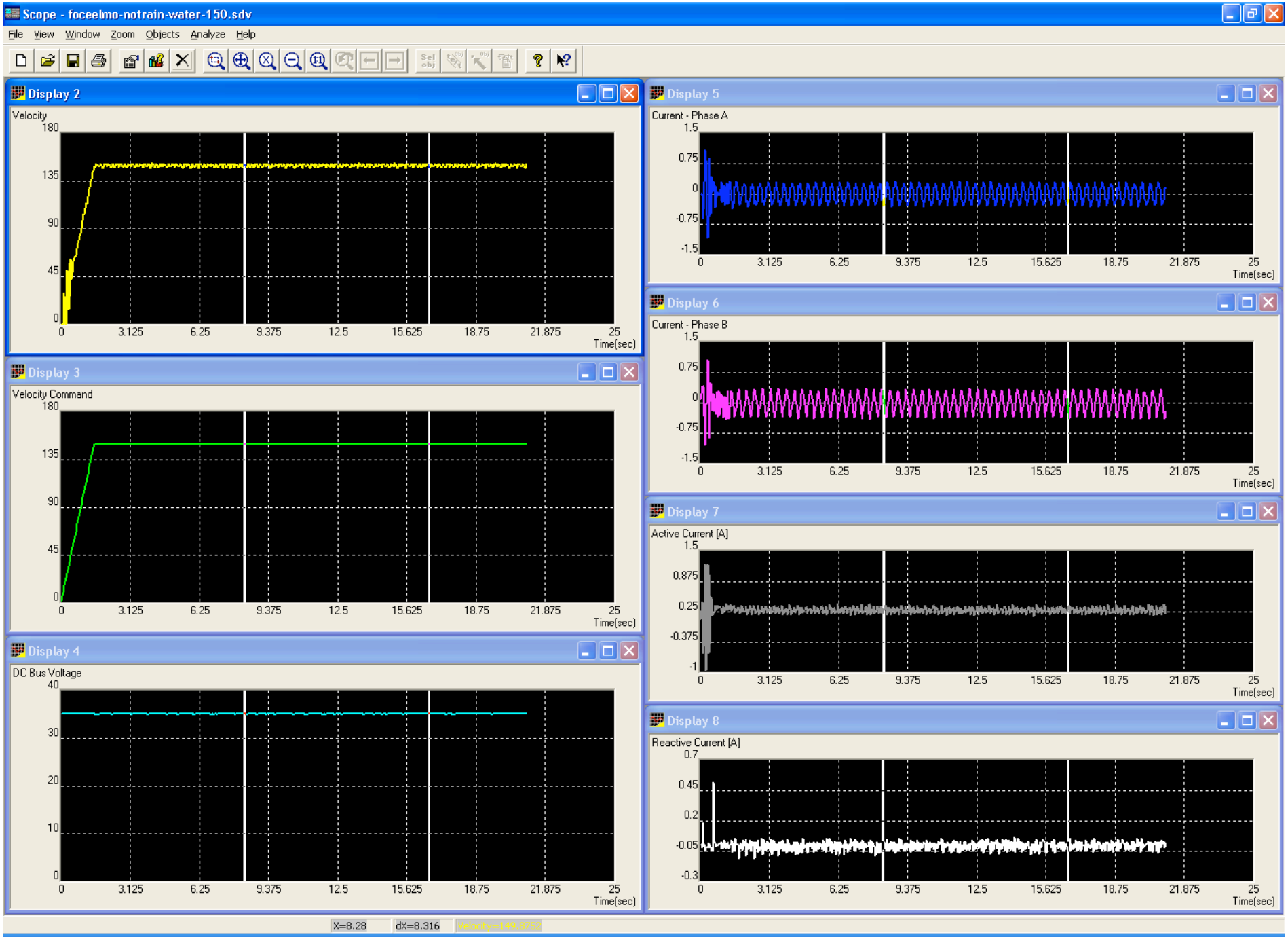
Motor w/ drive train, 300 c/s [4C water]



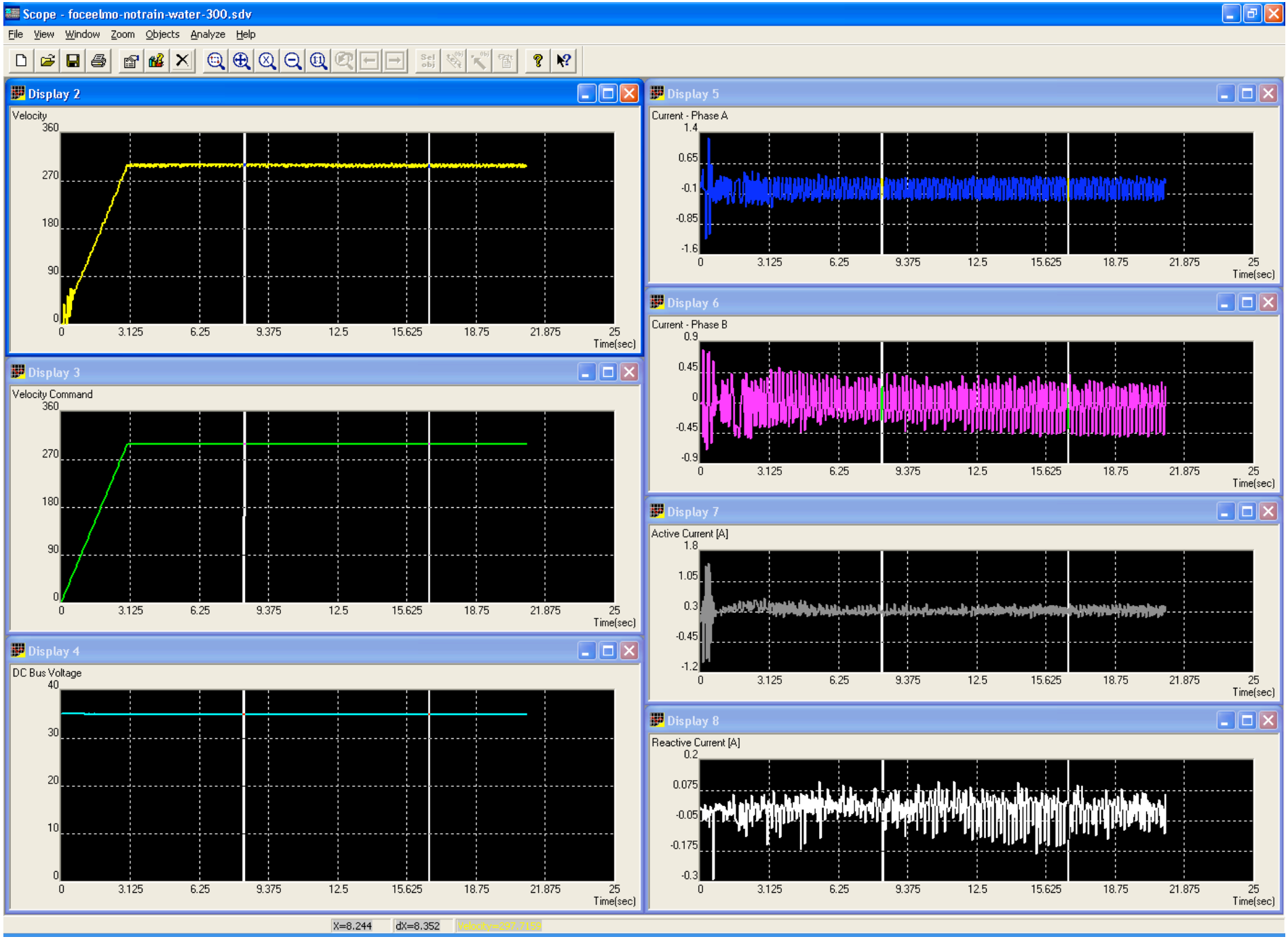
Motor w/ drive train, 150 c/s [10C air]



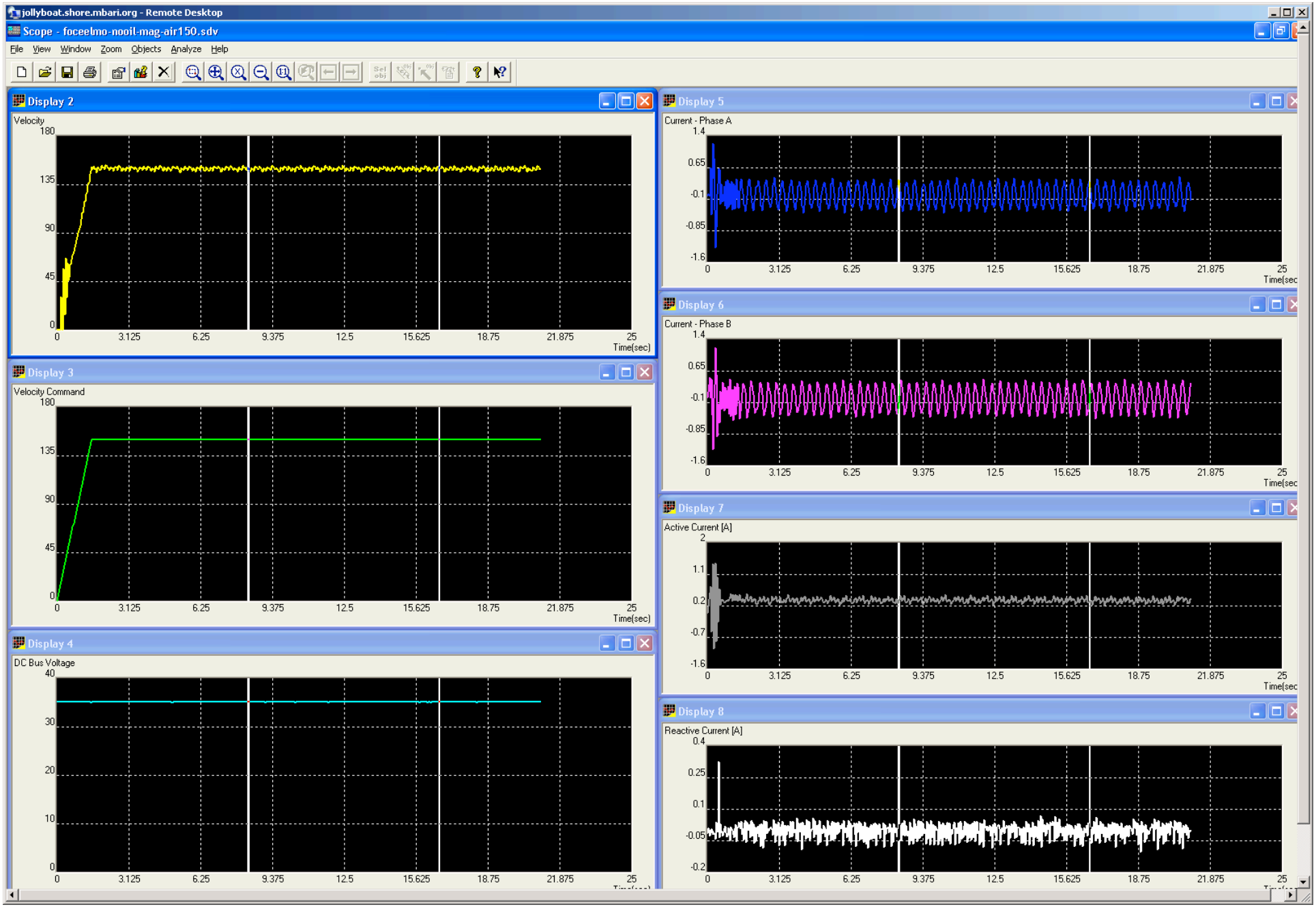
Motor w/ drive train, 300 c/s [10C air]



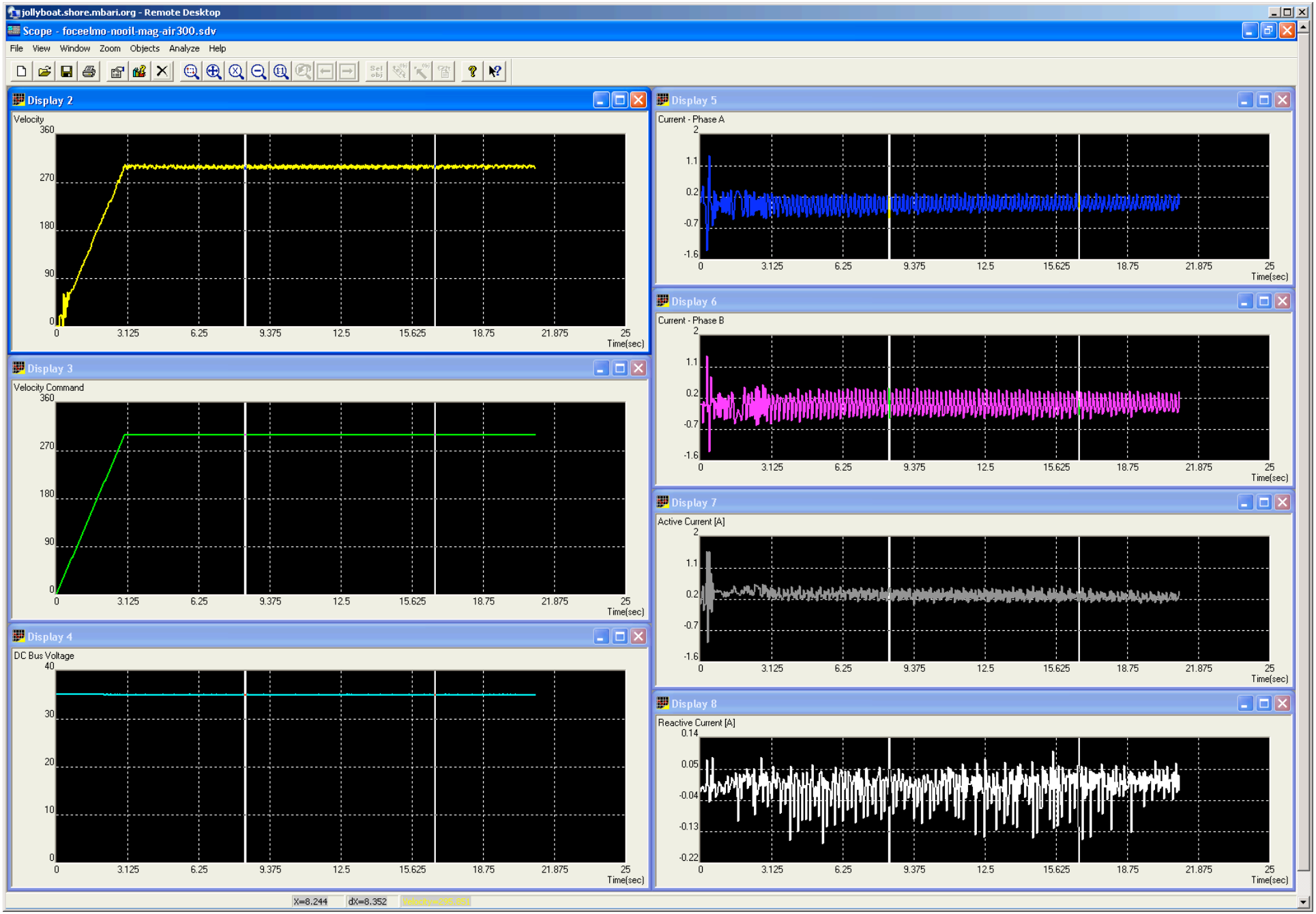
Motor w/o drive train, 150 c/s [4C water]



Motor w/o drive train, 300 c/s [4C water]



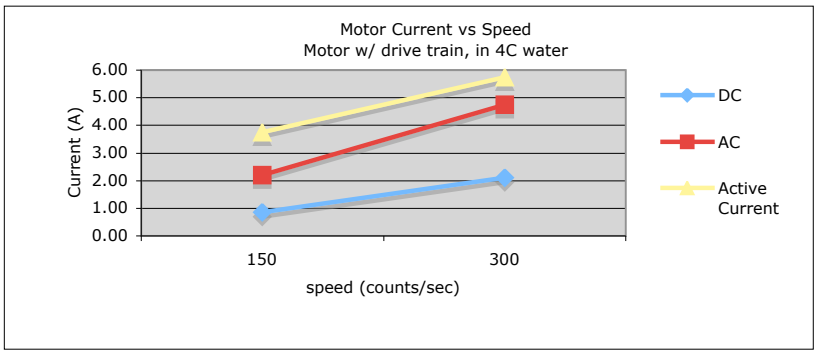
Motor w/o drive train w/o oil 150 c/s [10C air]

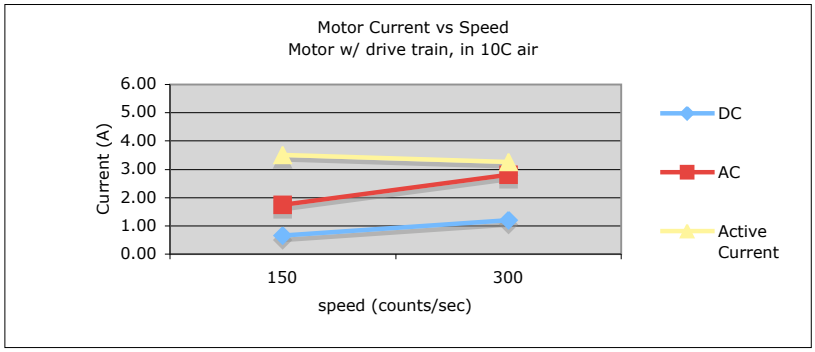


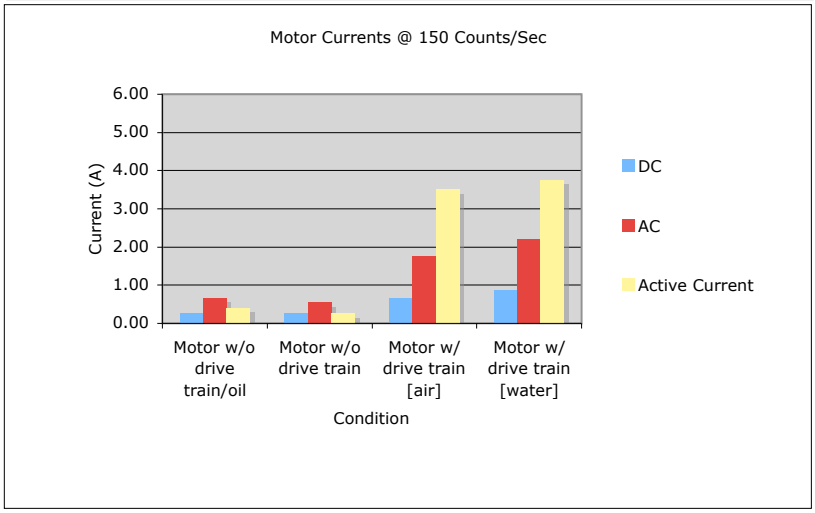
Motor w/o drive train w/o oil 300 c/s [10C air]

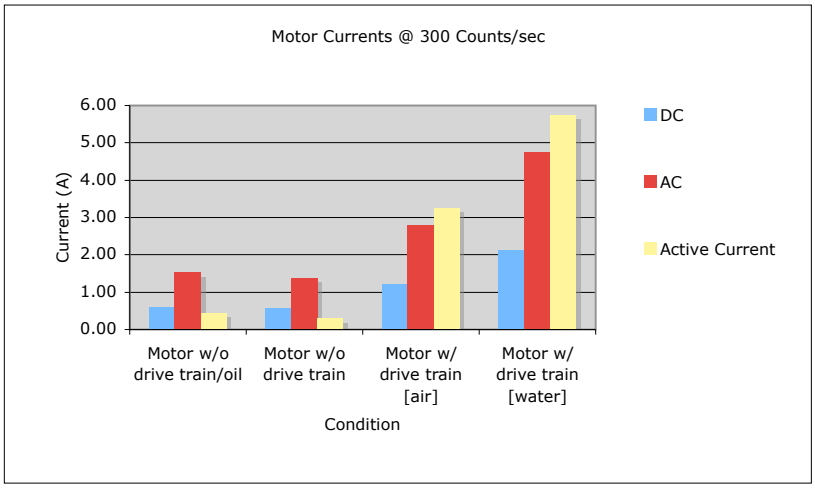
Condition	Speed	DC	AC	Active Current
Motor w/ drive train [water]	150	0.85	2.20	3.75
Motor w/ drive train [water]	300	2.10	4.75	5.75
Motor w/ drive train [air]	150	0.65	1.75	3.50
Motor w/ drive train [air]	300	1.20	2.80	3.25
Motor w/o drive train	150	0.25	0.53	0.25
Motor w/o drive train	300	0.56	1.37	0.30
Motor w/o drive train/oil	150	0.26	0.65	0.40
Motor w/o drive train/oil	300	0.60	1.52	0.45

Condition	Speed	DC	AC	Active Current	delta Idc	delta Iac	delta Iactive
Motor w/o drive train/oil	150	0.26	0.65	0.40	0%	0%	0%
Motor w/o drive train	150	0.25	0.53	0.25	-4%	-18%	-38%
Motor w/ drive train [air]	150	0.65	1.75	3.50	160%	230%	1300%
Motor w/ drive train [water]	150	0.85	2.20	3.75	31%	26%	7%
Motor w/o drive train/oil	300	0.60	1.52	0.45	0%	0%	0%
Motor w/o drive train	300	0.56	1.37	0.30	-7%	-10%	-33%
Motor w/ drive train [air]	300	1.20	2.80	3.25	114%	104%	983%
Motor w/ drive train [water]	300	2.10	4.75	5.75	75%	70%	77%


Motor Current vs Speed
Motor w/ drive train, in 4C water
Current (A)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
150
300
speed (counts/sec)
DC
AC
Active Current


Motor Current vs Speed
Motor w/ drive train, in 10C air
Current (A)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
150
300
speed (counts/sec)
DC
AC
Active Current


Motor Currents @ 150 Counts/Sec
Current (A)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Motor w/o drive train/oil
Motor w/o drive train
Motor w/ drive train [air]
Motor w/ drive train [water]
Condition
DC
AC
Active Current


Motor Currents @ 300 Counts/sec
Current (A)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Motor w/o drive train/oil
Motor w/o drive train
Motor w/ drive train [air]
Motor w/ drive train [water]
Condition
DC
AC
Active Current