Blade Testing Equipment Development and Commercialization

Cooperative Research and Development Final Report

CRADA Number: CRD-09-346

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Cooperative Research and Development Final Report

In accordance with Requirements set forth in Article XI.A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA Number: CRD-09-346

CRADA Title: Blade Testing Equipment Development and Commercialization

Parties to the Agreement: MTS Systems Corp

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources
Year 1	$ 163,000.00
Year 2	$ 00.00
Year 3	$ 00.00
TOTALS	$ 163,000.00

Abstract of CRADA work:

Blade testing is required to meet wind turbine design standards, reduce machine cost, and reduce the technical and financial risk of deploying mass-produced wind turbine models. NREL's National Wind Technology Center (NWTC) in Colorado is the only blade test facility in the U.S. capable of performing full-scale static and fatigue testing of multi-megawatt-scale wind turbine blades. Rapid growth in wind turbine size over the past two decades has outstripped the size capacity of the NWTC blade test facility leaving the U.S. wind industry without a suitable means of testing blades for large land-based and offshore turbines.

This CRADA will develop and commercialize testing technologies and test equipment, including scaling up, value engineering, and testing of equipment to be used at blade testing facilities in the U.S. and around the world.

Summary of Research Results:

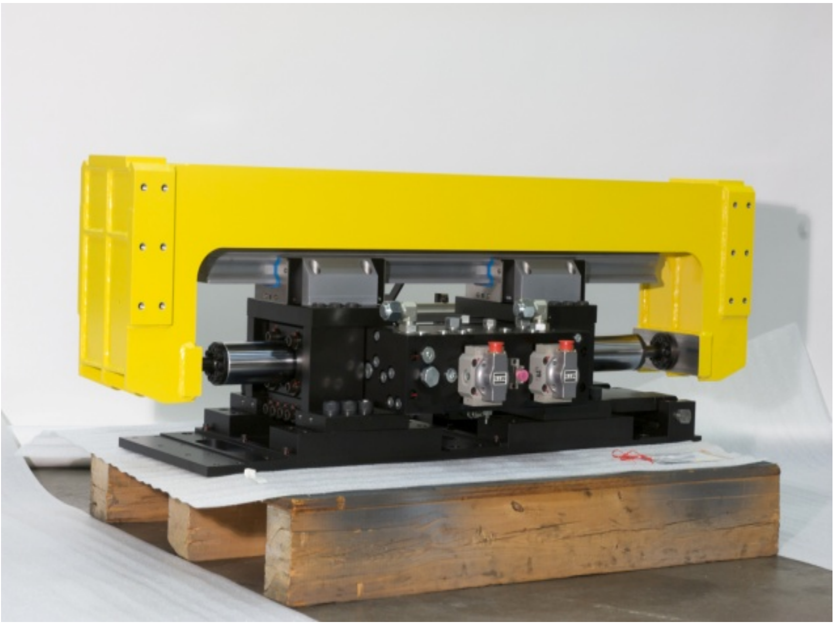
This CRADA resulted in the successful commercialization of a wind turbine blade fatigue test system. The hardware and control software for this fatigue test system were developed by MTS in collaboration with NREL. The system used for testing is called the Universal Resonance EXcitation (UREX) test system (see subsequent UREX photographs). MTS has sold UREX systems to multiple blade test labs as a result of this CRADA. The UREX is currently the only known wind turbine blade fatigue test system available in the market as a commercial product.

The UREX utilizes a blade test technology developed at NREL prior to this CRADA. This technology is a method of conducting accelerated fatigue tests of full-scale wind turbine blades. Testing is conducted at the fundamental resonant frequency of the blade test system. This technology provides an efficient means to input fatigue loads into a wind turbine blade test article. The loads are introduced to the test article through the oscillation of mass at the fundamental frequency. NREL licenses this technology to MTS for the UREX systems manufactured and sold by MTS.

The following activities were completed through this CRADA:

- MTS and NREL collaborated to develop a hardware specification for a resonant fatigue blade test system
- MTS developed a design for a resonant blade fatigue test system (UREX)
- NREL participated in a UREX design review at the MTS facility
- MTS developed a prototype UREX based on the NREL-developed resonant blade fatigue test technology
- MTS developed a resonant tracking algorithm
- NREL tested the prototype UREX and resonant tracking algorithm on a full-scale 50-meter wind turbine blade (see subsequent completed test matrix)
    - UREX was controllable and tunable
    - UREX capable of inputting loads for 50m blade fatigue test
    - Resonant tracking algorithm capable of automatically tracking blade resonance during test
- MTS commercialized prototype UREX based on NREL developed resonant test technology

Below are several photographs of the commercial UREX system.



Commercial MTS UREX resonant blade fatigue test system module developed under CRADA (PIX 17637)

Dual-station UREX configuration for flapwise fatigue test to 50m blade (PIX 20448)

UREX configured for edge-wise fatigue test to 50m blade (PIX 20445)

As series of tests demonstrating the performance of the MTS UREX system were conducted at NREL, at the National Wind Technology Center near Boulder, Colorado. These trials were developed to test the UREX system under conditions and events that would normally be observed during blade testing of mega-watt scale blades. Testing was conducted on a 50-m blade used for a 2+ MW machine. Raw data from the testing is proprietary to the blade manufacturer.

Initial testing focused on flapwise testing, where the UREX actuators were aligned in the blade's flapwise orientation, providing load excitation (actuator displacement) at the system's flapwise natural frequency. During the initial testing, the system was tuned for safe and stable operation. Tuning included programming the MTS servo-control system parameters and feedback systems to obtain a stable control which matched the desired command. The primary sensor used for feedback in the testing was an accelerometer. System hydraulics were tuned through adjustments to accumulator preload settings. The interface between the MTS hydraulic controller and the data acquisition system was checked and verified to have proper communication. The initial test runs used a light oscillating mass attached to the UREX actuators, about 170 kg for each actuator, ramping the displacement of the UREX actuators. For each increment of oscillating weight the system was demonstrated to be stable. Load cases were run to establish the sensitivity of the response to the control frequency.

Once operation at target test loads was achieved, the test matrix was expanded to include operational cases to include off-resonant operation, edgewise, torsional, and combined loading cases. The system was operated varying the frequencies and displacements of the UREX actuators to achieve pure edgewise loads with flap excitation. Dual axis cases were tested and evaluated by running one UREX actuator at the flap natural frequency and one at the edge natural frequency. Similar testing was conducted at the flap, edge, and torsional natural frequencies. Cases were run whereby the phase lag between actuators was modified. The MTS resonant tracking software was demonstrated for several load cases. The following table provides a top-level view of the load cases performed during the demonstration test.

Table 1 – Completed Test Matrix (in chronological order)

Date & Time	UREX mass x2 total (kg)	Actuator Stroke (±mm)	UREX frequency (Hz)	Test Notes
110517 1039	170	30	(approx flap resonance)	1st flap
110517 1120	170	30	(approx flap resonance)	Same as 110517_1039, but stop hydraulics.
110517 1536	170	30	(approx flap resonance)	1st flap
110517 1606	170	60	(approx flap resonance)	1st flap
110517 1623	170	90	(approx flap resonance)	1st flap
110517 1641	170	120	(approx flap resonance)	1st flap
110517 1708	170	150	(approx flap resonance)	1st flap
110517 1715	170	140	(approx flap resonance)	1st flap

Date & Time	UREX mass x2 total (kg)	Actuator Stroke (±mm)	UREX frequency (Hz)	Test Notes
110517 1721	170	140 ramp up	(approx flap resonance)	Ramp up actuator stroke
1105181002	170	140	(approx flap resonance)	1st flap
1105181012	170	140	(+1% flap resonance)	1st flap
1105181021	170	140	(+2% flap resonance)	1st flap
1105181031	170	140	(+3% flap resonance)	1st flap
1105181048	170	140	(-1% flap resonance)	1st flap
1105181058	170	140	(-2% flap resonance)	1st flap
1105181108	170	140	(-3% flap resonance)	1st flap
110519 0930	420	56	(approx edge resonance)	Edge excite
110519 1005	420	30	(approx flap resonance)	1st flap
110519 1019	420	60	(approx flap resonance)	1st flap
110519 1033	420	90	(approx flap resonance)	1st flap
110519 1050	420	120	(approx flap resonance)	1st flap
110519 1106	420	140	(approx flap resonance)	1st flap
110519 1755	670	30	(approx flap resonance)	1st flap
110520 0854	670	45	(approx flap resonance)	1st flap
110520 0906	670	30	(approx flap resonance)	1st flap
110520 0918	670	60	(approx flap resonance)	1st flap
110520 0929	670	75	(approx flap resonance)	1st flap
110520 0940	670	90	(approx flap resonance)	1st flap
110520 0950	670	105	(approx flap resonance)	1st flap
110520 1001	670	120	(approx flap resonance)	1st flap
110520 1122	670	60	(approx flap resonance)	LE actuator lags TE actuator by 45°.
110520 1134	670	60	(approx flap resonance)	LE actuator lags TE actuator by 90°.
110520 1145	670	60	(approx flap resonance)	LE actuator lags TE actuator by 135°.
110520 1156	670	60	(approx flap resonance)	LE actuator lags TE actuator by 180°.
110520 1411	670	45	(approx edge resonance)	Edge excite
110520 1432	670	60	(LE actuator) (TE actuator)	Dual axis
110520 1447	670	60	(LE actuator) (TE actuator)	Dual axis
110520 1506	670	60	0 (LE actuator) 0 (TE actuator, 72° phase lag)	Actuator phase lag
110523 1648	1020	50.8		Resonant search

Date & Time	UREX mass x2 total (kg)	Actuator Stroke (±mm)	UREX frequency (Hz)	Test Notes
110524 1030	1020	50.8		Resonant tracking
110524 1042	1020	50.8		Resonant search
110524 1139	1020	50.8		Resonant tracking
110524 1157	1020	50.8		Resonant tracking
110524 1211	1020	30 & 15	0.1 to 1.44 Frequency sweep	Frequency sweep
110524 1355	1020	15	(approx flap resonance)	1st flap
110524 1403	1020	30	(approx flap resonance)	1st flap
110524 1409	1020	40	(approx flap resonance)	1st flap
110524 1415	1020	50	(approx flap resonance)	1st flap
110524 1420	1020	60	(approx flap resonance)	1st flap
110524 1425	1020	70	approx flap resonance)	1st flap
110524 1437	1020	50.8		Resonant tracking
110524 1534	1020	Varied	0.601 to 0.92 (sweep)	Sweep demonstration
110524 1648 to 1911	1020	50.8		Resonant search and tracking
110525 1512	1020	50.8		Resonant tracking
110526 0931	1020	2	(approx 2nd flap resonance)	2nd flap excite
110526 0947	1020	5	(approx 2nd flap resonance)	2nd flap excite
110526 1010	1020	5	1.42 to 3.7 (sweep)	Frequency sweep
110526 1458	1020	1 (LE) 5 (TE)	(LE) (TE)	1st and 2nd flap simultaneous
110526 1506	1020	1 (LE) 10 (TE)	(LE) (TE)	1st and 2nd flap simultaneous
110526 1514	1020	2 (LE) 10 (TE)	(LE) (TE)	1st and 2nd flap simultaneous
110526 1521	1020	3 (LE) 10 (TE)	(LE) (TE)	1st and 2nd flap simultaneous
110526 1527	1020	3 (LE) 15 (TE)	(LE) (TE)	1st and 2nd flap simultaneous
110527 0922	1020	10 (LE) 10 (TE)	(LE) (TE)	Dual axis
110527 0930	1020	10 (LE) 30 (TE)	(LE) (TE)	Dual axis
110527 0942	1020	20 (LE) 30 (TE)	(LE) (TE)	Dual axis
110527 0955	1020	30 (LE) 30 (TE)	(LE) (TE)	Dual axis
110527 1013	1020	30 (LE) 40 (TE)	(LE) (TE)	Dual axis
110527 1022	1020	40 (LE) 40 (TE)	(LE) (TE)	Dual axis
110527 1030	1020	0 (LE) 40 (TE)	(LE) (TE)	Dual axis

Date & Time	UREX mass x2 total (kg)	Actuator Stroke (±mm)	UREX frequency (Hz)	Test Notes
110527 1037	1020	1 (LE) 40 (TE)	(LE) (TE)	1st flap and torsion simultaneously
110527 1311	1020	1	3.0 (180° phase shift between each actuator)	Torsion with 180° phase shift between actuators
110527	1020	?	?	1st and 2nd flap (PV algorithm check)

Subject Inventions Listing:

none

Report Date:

November 30, 2012

Responsible Technical Contacts at Alliance/NREL:

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