BWR Owners' Group
DC Motor Methodology

Presentation for NRC Meeting

August 30, 2000

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Purpose of Presentation

- Provide program status
- Describe key program elements

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Primer

- Not seeking formal NRC review
- Issue: Motor speed/output torque affected by stem load, supplied voltage and winding temperature.
- Potential impact:
  - Longer MOV stroke times
  - Lower motor output (torque), thus lower valve thrust

Drivers for BWROG Action

- INEEL testing raised issues
- Actuator efficiency decreases at slower motor speeds
- BWROG wanted to be proactive in issue resolution

Methodology Development

- MPR Associates selected by BWROG to assist in methodology development
- Limitorque Corporation has cooperated from beginning of effort
- BWROG utilities provided input and guidance on final methodology; approved final report (Feb 00)
- Final report issued to BWROG utilities in Mar 00
- BWROG requested endorsement from Limitorque
- BWROG has made methodology available to entire industry
- BWROG conducted utility training on methodology in Jun 00

NRC Interface

- Have kept NRC briefed on program status:
  - Apr 99, Oct 99 & Apr 00 JOG PV-NRC Status Meetings
  - Aug 99, Dec 99 & Mar 00 EOC-NRC Management Meetings
  - Paper presented at Jul 00 NRC/ASME Pump & Valve Symposium
- Supplied methodology to Staff for information prior to this meeting
- NRC has supported BWROG schedule & requested Aug 00 meeting to discuss details of methodology.

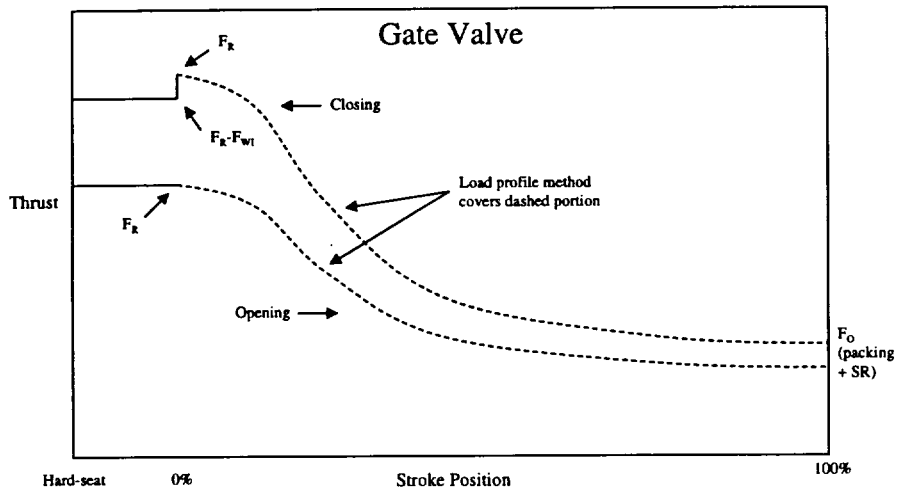
Description of Method

- Evaluations are performed incrementally through the valve stroke. At each stroke position:
  - Required thrust is determined (load profile method or user-input)
  - Motor torque is calculated (stem factor, gear ratio and actuator efficiency method)
  - Motor current and terminal voltage are determined (vendor performance curves, electrical calculation)
  - Motor speed is calculated (DC motor model)
  - Incremental time is calculated
  - Motor heat-up is calculated (vendor performance data/curve)

Description of Method (Con't)

- Load profile method
  - Uses results from EPRI MOV program for gate valves
  - Assumes C_V linear with stroke for globe valves
  - Considers overall system equivalent resistance for incompressible flow and system equivalent length for compressible flow (gate valves only)
  - Result is a "family" of load profile curves, which are tabulated for use in the method
  - Potential influence of water inertia included
  - The load profile provides the valve stem thrust at the beginning and end of each stroke increment; average stem thrust for an increment used to evaluate incremental time

Description of Method (Con't)



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Description of Method (Con't)

- Average motor torque calculated from average stem load

$$\tau = \frac{F * SF}{OAR * \eta}$$

  - F: Stem thrust, lbs (from load profile method)
  - SF: Stem factor, inches (user-input)
  - OAR: overall ratio (user-input)
  - η = f(worm speed, stem torque)

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Description of Method (Con't)

- Gearbox Efficiency

$$\eta = \eta_P + f(\eta_R - \eta_P)$$

  - η_P: Pullout efficiency
  - η_R: Run efficiency
  - f-factors

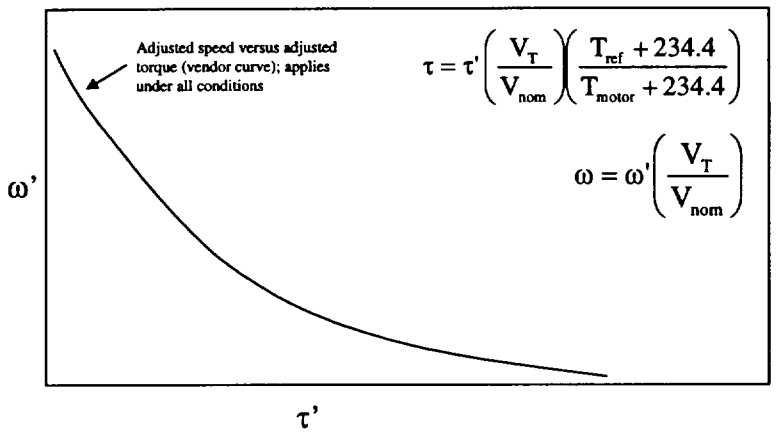
Worm Speed (rpm)	Efficiency Factor "f" for a ($\tau_{S\text{-}ave}/\tau_{rated}$) of:	
	0.00	≥0.30
0	-0.6	-0.6
100	-0.2	-0.2
450	-0.2	0.4
≥2000	-0.2	0.7

Description of Method (Con't)

- Motor current
  - From vendor performance curve, as a function of motor torque
- Motor speed versus torque
  - Function of terminal voltage and winding temperature
    - Terminal voltage calculated from MCC voltage (user-input), cable resistance from MCC to MOV, thermal overload resistance and motor current
    - Motor winding temperature calculated from ambient temperature and motor heatup
  - Relationship under all conditions can be described by a single curve of adjusted speed versus adjusted torque

Description of Method (Con't)

Adjusted Speed versus Adjusted Torque



$$\tau = \tau' \left(\frac{V_T}{V_{nom}} \right) \left(\frac{T_{ref} + 234.4}{T_{motor} + 234.4} \right)$$

$$\omega = \omega' \left(\frac{V_T}{V_{nom}} \right)$$

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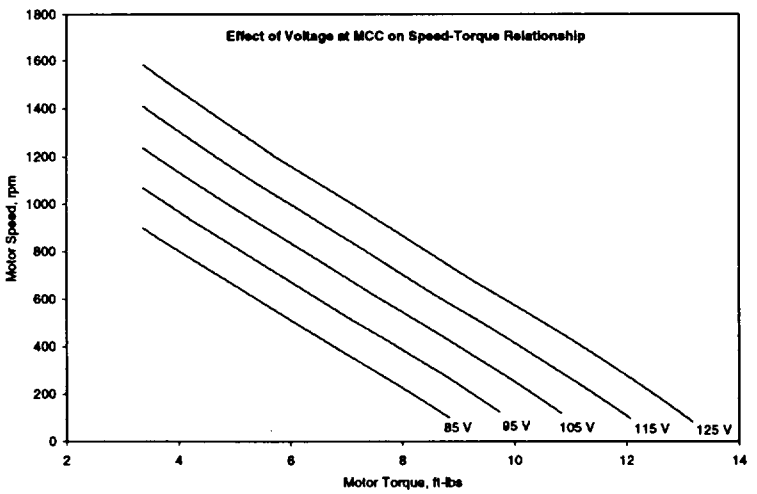
Description of Method (Con't)



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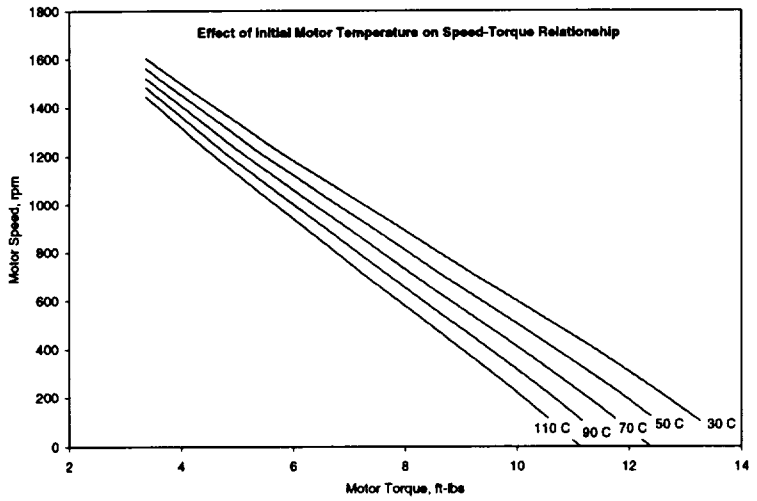

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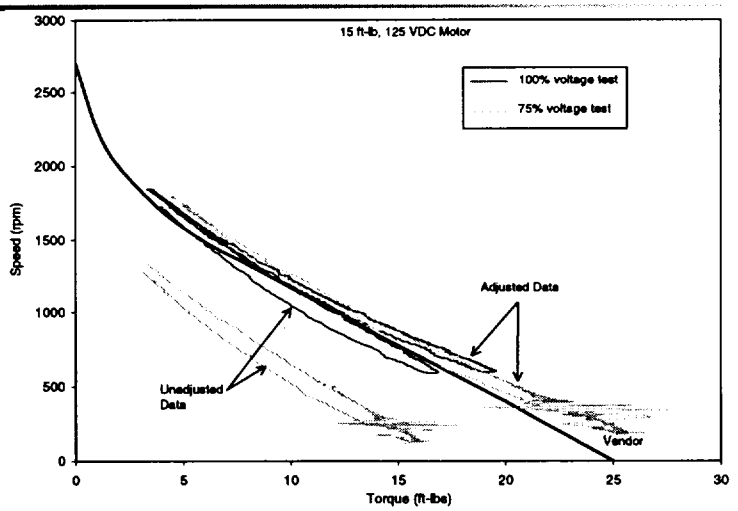

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Description of Method (Con't)

- Motor Heatup
  - Heatup occurs due to resistive losses in the motor
  - Vendor-supplied heatup rates are used in method

$$\Delta T = \Delta t * h_{ref}\left(\frac{\tau}{\tau_{ref}}\right)^2$$

  - Heatup added to temperature at beginning of increment
- Predicted Stroke Time
  - Time for each stroke increment calculated from increment length, motor speed, stem lead, actuator overall ratio
  - Total stroke time is sum of all increment stroke times

Description of Method (Con't)

- Instantaneous Actuator Capability and Margin
  - The capability of the actuator, at any given stroke position, based on the nominal motor torque, adjusted for degraded voltage and elevated temperature at that stroke position; uses efficiency at that stroke position

$$AC_{inst} = \tau_{nom} * \left(\frac{OAR * \eta}{SF}\right)\left(\frac{V_T}{V_{nom}}\right)\left(\frac{T_{ref} + 234.4}{T_{motor} + 234.4}\right)$$

  - Instantaneous margin at each stroke position calculated as difference between required stem thrust and instantaneous actuator capability

Description of Method (Con't)

- Functional Actuator Capability and Margin
  - The highest value of maximum required stem thrust the actuator can overcome, specific to a given valve stroke
  - Functional actuator capability by iteratively increasing required stem thrust until maximum value of adjusted motor torque at any point during stroke equals nominal motor torque
  - Functional margin calculated as the difference between the functional actuator capability and the original required stem thrust for the stroke

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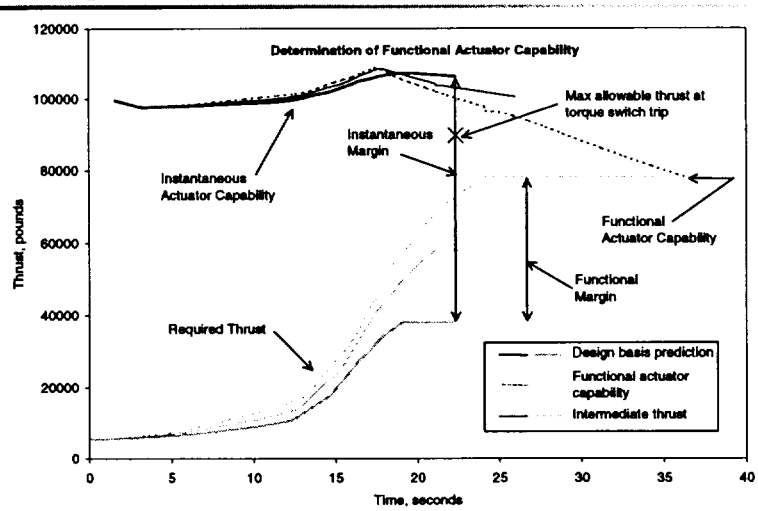
Description of Method (Con't)



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Description of Method (Con't)

- Maximum Allowable Thrust at Torque Switch Trip
  - Calculated from nominal motor torque, adjusted for degraded voltage (based on current at nominal motor torque), temperature at last stroke position; efficiencies based on calculated motor speed and stem load

$$T_{TST-max} = \tau_{nom} * \left(\frac{OAR * \eta}{SF}\right)\left(\frac{V_T}{V_{nom}}\right)\left(\frac{T_{ref} + 234.4}{T_{motor} + 234.4}\right)$$

  - Same as instantaneous actuator capability except
    - Only evaluated at last stroke position of a closing stroke
    - η and V_T adjusted for "actual" current and torque at torque switch trip

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Description of Method (Con't)

- Maximum Allowable Thrust at Unwedging
  - Calculated from nominal motor torque, adjusted for degraded voltage (based on current at nominal motor torque), temperature at first stroke position; efficiencies based on calculated motor speed and stem load

$$T_{UNW-max} = \tau_{nom} * \left(\frac{OAR * \eta}{SF}\right)\left(\frac{V_T}{V_{nom}}\right)\left(\frac{T_{ref} + 234.4}{T_{motor} + 234.4}\right)$$

  - Same as instantaneous actuator capability except
    - Only evaluated at first stroke position of a gate valve opening stroke
    - η and V_T adjusted for "actual" current and torque at unwedging

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Description of Method (Con't)

Expected Use of Method Output

Opening Stroke (limit switch control)	**Closing Stroke** (limit switch control)	**Closing Stroke** (torque switch control)
• stroke time • functional actuator capability • max allowable thrust at unwedging	• stroke time • functional actuator capability	• stroke time • max allowable thrust at TST

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Description of Method (Con't)

- Screening method for high margin valves
  - Simplified (easier) approach for high margin valves
  - Predicted motor speed must be ≥1000 rpm
  - Max stroke time and min actuator capability determined
    - Approach is to use maximum required thrust for the full stroke, rather than using the load profile method
    - Other simplifications are used but can be eliminated by user through iteration
      - Pullout efficiency
      - Locked rotor current
      - Motor temperature is ambient plus 15C
        - » Verified once stroke time is determined

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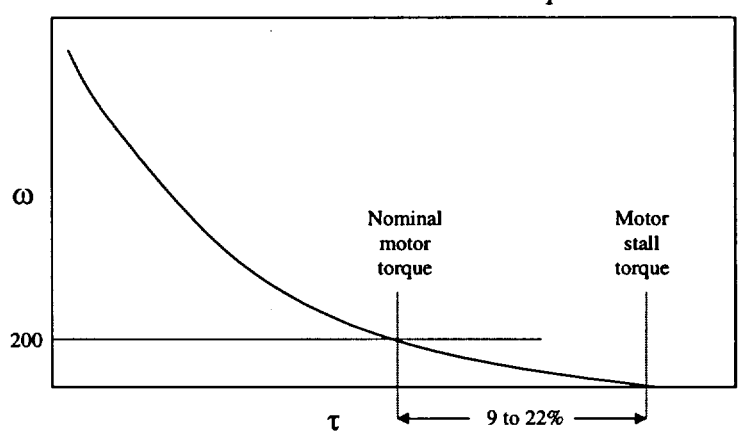
Method Justification

- Use of nominal motor torque (τ_{nom})
  - Defined as motor torque at speed of 200 rpm
  - Used as motor torque limit in method
  - Provides margin to ensure motor doesn't stall
  - Determined from vendor motor performance curve (or alternate values defined in method)
  - Results in typically margin against stall of 9 to 22%
  - Test data show that torques greater than τ_{nom} are achieved before motor stall

Method Justification (Con't)

Use of Nominal Motor Torque



Method Justification (Con't)

- Use of vendor motor performance curves
  - Motor dynamometer and actuator test data obtained to justify use of vendor motor performance curves
  - Measured speed versus torque adjusted using first principles motor model and plotted versus vendor curves
  - For most motors for which data were available, vendor curves bound test data
  - For three motors, the vendor speed versus torque curves did not adequately model the measured data. For these motors, new curves based on the test data are recommended for use in the method.
    - Vendor has questioned whether appropriate motor curves were used; currently being reviewed

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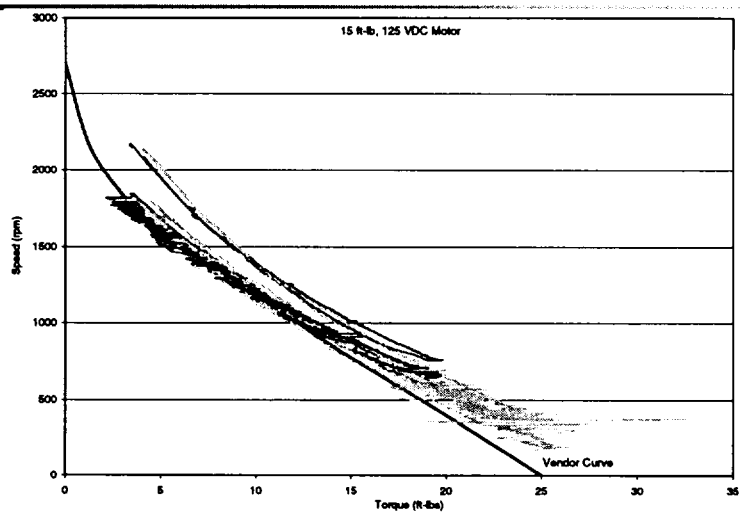
Method Justification (Con't)



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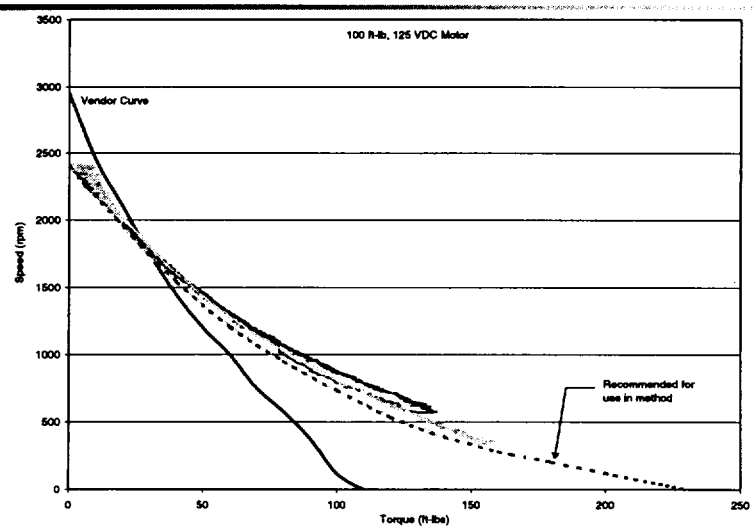

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Method Justification (Con't)

- Gearbox Efficiency Method
  - Efficiency f-factor defined based on run efficiency (η_R) and pullout efficiency (η_P)

$$f = \frac{\eta - \eta_P}{\eta_R - \eta_P}$$

  - f-factor of 0 results in efficiency equal to pullout efficiency
  - f-factor of 1 results in efficiency equal to run efficiency

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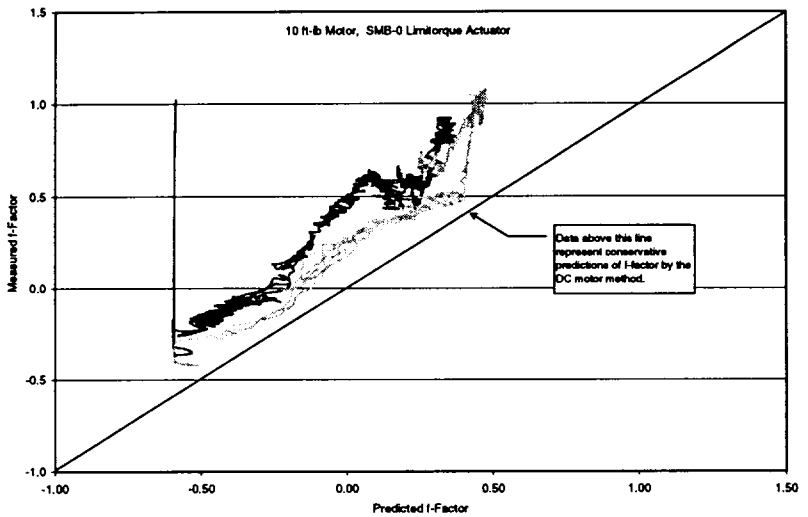
Method Justification (Con't)

- Gearbox Efficiency Method (Con't)
  - f-factors determined from test data; f-factors are a function of the rotational speed of the worm shaft and output torque of the actuator
    - Efficiency is low (below pullout efficiency) for low stem torques (< 30% of rated actuator torque) and low worm speeds (< 200 rpm)
    - For stem torques > 30% actuator rated torque, efficiency is insensitive to stem torque
    - For torques greater than 30% of actuator rated torque and speeds above 200 rpm, efficiency greater than pullout is used
    - Upper bound f-factor of 0.7 based on test data

Method Justification (Con't)

- f-factors validated by comparison to NRC/INEEL test data
  - SMB-0 and SMB-1 actuators
  - 10 ft-lb, 25 ft-lb and 40 ft-lb motors
  - 60% and 100% voltage
- The results indicate that the efficiencies applied in the method are generally conservative

Method Justification (Con't)



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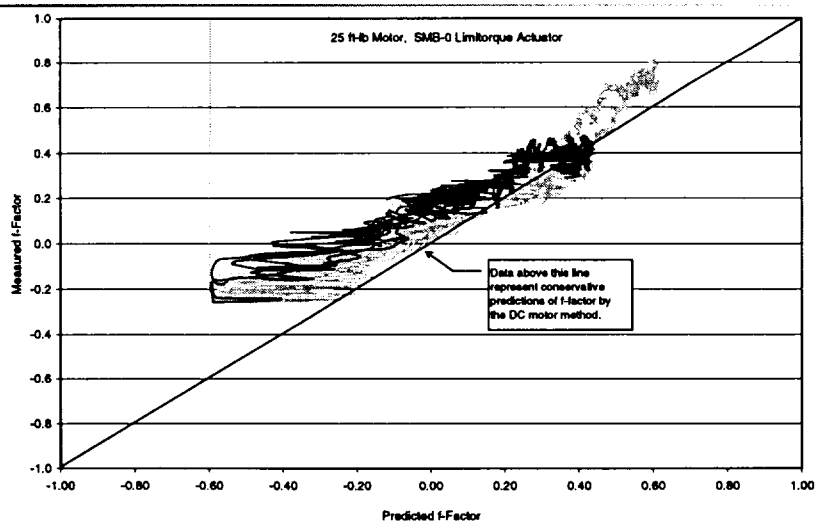

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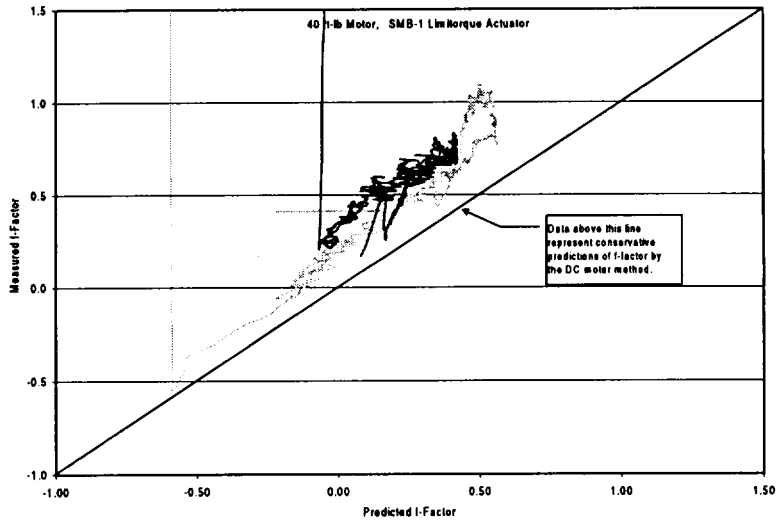

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Method Justification (Con't)

- Motor heatup
  - Limited data for validation
  - NRC/INEEL data used
    - 10, 25 and 40 ft-lbs motors
    - 60% and 100% voltage tests
  - Method implemented for these tests, and predicted temperature rises compared to measured temperature rises
  - Results show that method is reasonable and conservative

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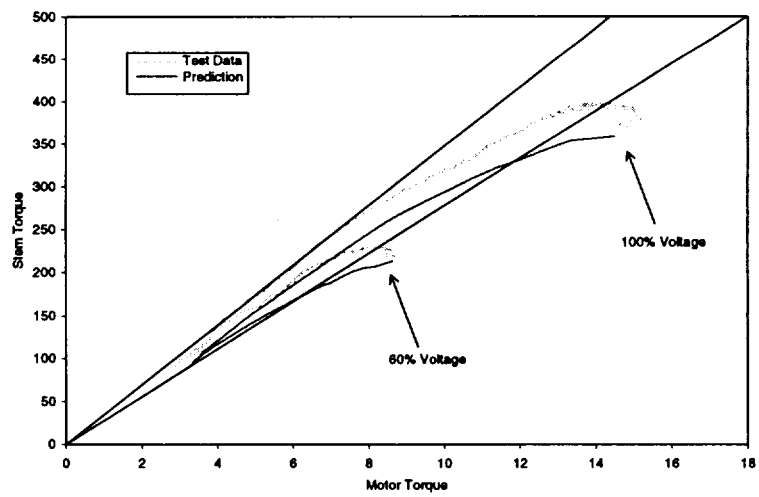
Method Justification (Con't)

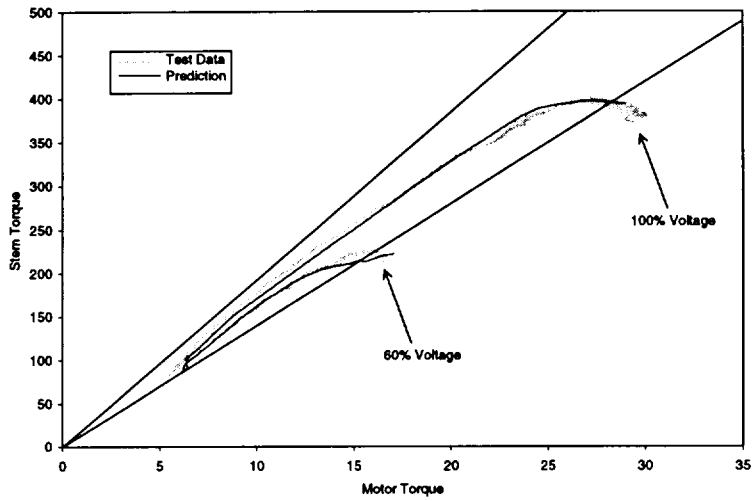
- Measured versus predicted temperature rise

Motor/Test	Measured Temperature Rise, °F	Predicted Temperature Rise, °F
10 ft-lbs, 60% voltage	23	30 @ 74 rpm
10 ft-lbs, 100% voltage	40	44 @ 75 rpm
25 ft-lbs, 60% voltage	45	68 @ 103 rpm
25 ft-lbs, 100% voltage	80	97 @ 161 rpm
40 ft-lbs, 60% voltage	negligible	24 @ 236 rpm
40 ft-lbs, 100% voltage	40	55 @ 120 rpm

Comparison to INEEL Data - 10 ft-lb Motor



Comparison to INEEL Data - 25 ft-lb Motor



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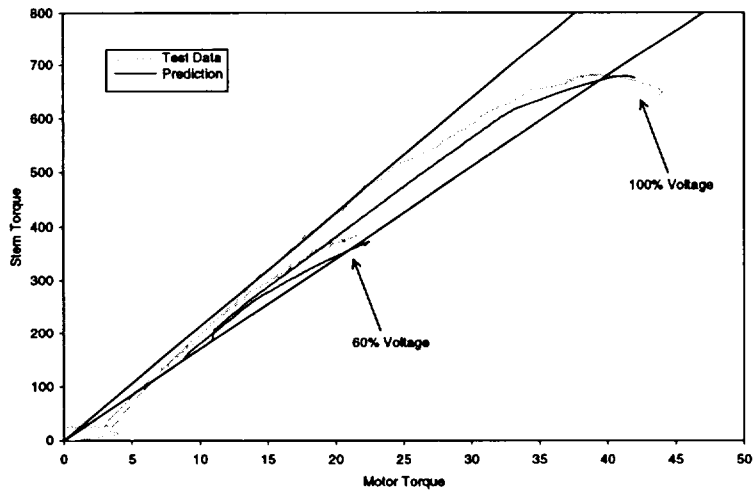
Comparison to INEEL Data - 40 ft-lb Motor



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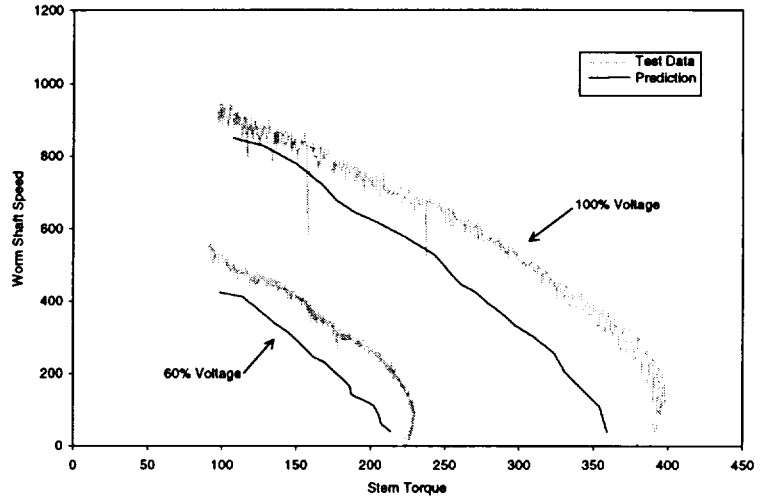
Comparison to INEEL Data - 10 ft-lb Motor



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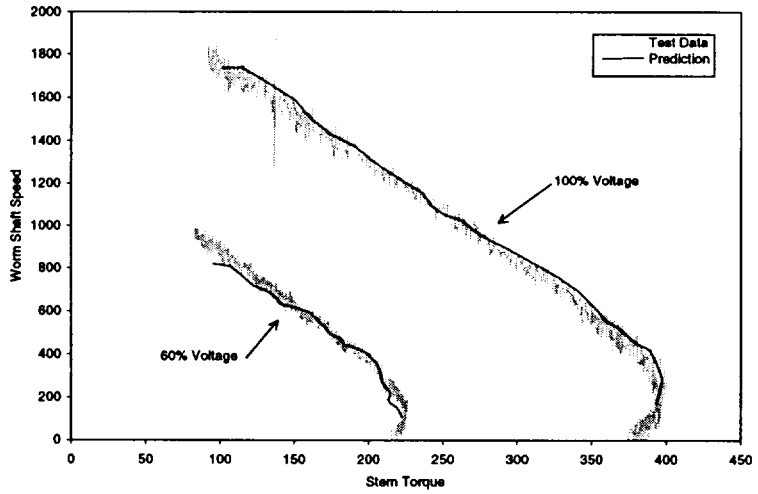
Comparison to INEEL Data - 25 ft-lb Motor



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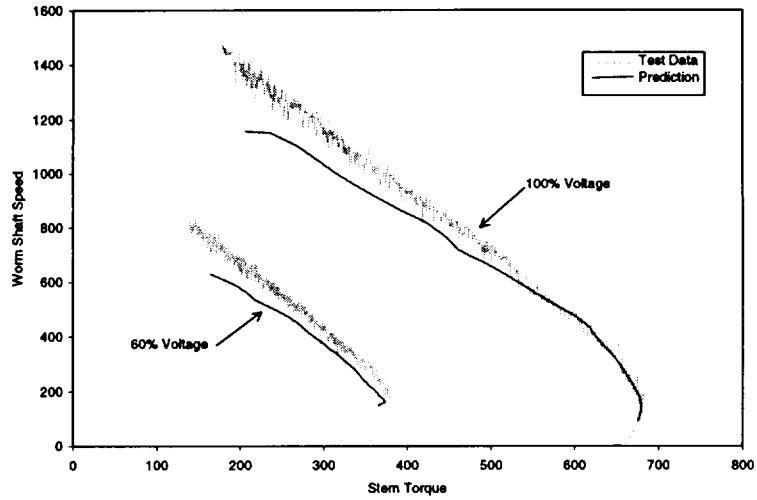
Comparison to INEEL Data - 40 ft-lb Motor



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Method Validation

- Test data from in-plant valve flow tests was obtained for model validation
  - Seven MOVs from four utilities
  - 22 valve strokes (11 static, 11 DP strokes)
  - Wedge gate, double disk gate and globe valves
  - Six different actuator types and four different motor types (all Peerless)
  - Pumped flow opening and closing strokes, steam flow opening and closing strokes, and a hydrostatic opening stroke
  - All tests performed at ambient temperature

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Method Validation (Con't)

- Results
  - The predicted stroke times bound the measured stroke times for 20 of the 22 strokes
  - For two of the strokes, the predicted stroke times are within 2% of the measured stroke times
    - Slight overpredictions are considered acceptable

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Method Validation (Con't)

Plant	Valve Type	Actuator and Motor Type	General Test Conditions	Voltage at MCC (volts)	Stroke Time (sec)	
					Measured	Predicted
BWR Plant B	Double disk gate	SMB-2, 60 ft-lb, 250 VDC	static closure	265	16.6	17.9
			static opening	265	16.1	17.8
			steam flow closure	265	16.2	20.0
			steam flow opening	265	16.3	20.0
BWR Plant C	Flex wedge gate	SMB-1, 60 ft-lb, 250 VDC	static closure	268	28.1	33.5
			static opening	268	27.2	33.6
			steam flow closure	268	31.5	38.3
			steam flow opening	268	28.2	35.3
BWR Plant D	Flex wedge gate	SMB-0, 40 ft-lb, 250 VDC	static closure	261	10.5	10.3
			static opening	261	9.7	11.1
			pumped flow closure	210	13.4	14.5
			pumped flow opening	210	12.9	16.2
BWR Plant D	Globe	SMB-2, 60 ft-lb, 250 VDC	static closure	262	11.3	11.6
			pumped flow closure	210	14.3	14.6
BWR Plant D	Flex wedge gate	SMB-00, 15 ft-lb, 125 VDC	static opening	130	12.0	12.0
			hydrostatic opening	106	15.6	15.5
BWR Plant D	Globe	SMB-000, 2 ft-lb, 125 VDC	static closure	130	24.2	24.2
			pumped flow closure	106	31.0	31.6
BWR Plant E	Double disk gate	SMB-1, 40 ft-lb, 250 VDC	static closure	250	12.4	15.0
			static opening	250	12.3	15.5
			steam flow closure	250	14.9	22.3
			steam flow opening	250	10.4	17.6

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Summary

- Awaiting Limitorque endorsement
- Utilities have been requested to begin valve assessments using BWROG methodology when methodology has been accepted by NRC
- Utility implementation schedule currently being reviewed by BWROG for recommendation to the NRC