RECLAMATION

Managing Water in the West

PAP-1042
Data Report – Compiled by K.W. Frizell and J. Mortensen

Torque Measurements on various butterfly valves at Durango Pumping Plant

November 7-9, 2011

U.S. Department of the Interior
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Technical Service Center
Hydraulic Investigations and Laboratory Group
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Introduction

Initial operation of the Durango Pumping Plant revealed several issues related to operation of the butterfly valves used as the pump discharge valves and guard valves on each of the plant's pumping units. There are 3 different sizes of these valves within the plant; 36-in valves on the large pumping units (5-8), 24-in valves on the medium pumping units (3-4), and 18-in valves on the small pumping units (1-2). On all units the pump discharge valves are motor-operated and the guard valves are manually operated (with the exception of units 1 and 2 which have motor operators). The butterfly valves are all ¼ turn full stroke valves and are mounted with the axis of the shaft horizontal. Each features a gear box connected to the valve shaft and then to either the motor operator or a hand wheel.

The purpose of this data report is to transmit all data collected during a field trip to Durango Pumping Plant where strain gage rosettes designed to measure torque (torsion) were installed on the valves of Units No. 1, 3, 5, and 6. Standard operation of each type of valve was attempted and results recorded. In addition some variations to the standard operations were attempted. When possible, each of the pump discharge valves and the guard valves were operated under balanced head conditions (equalized pressure on either side of the valve) and fully unbalanced head conditions (maximum pressure differential across the valves). Pressure gages do not currently exist within the system to measure these actual conditions. Under some of the test cases, the amount of imbalance was not known exactly – especially if any leakage was occurring across the discharge valve, check valve, or guard valve. The basic assumption made was for drop tight seals (no leakage) on the butterfly valves and observation of the indication on the flap-type check valve was noted.

Test Equipment and Theory

The strain gages selected and installed were CEA-06-187UV-350/P2 (figure 1).

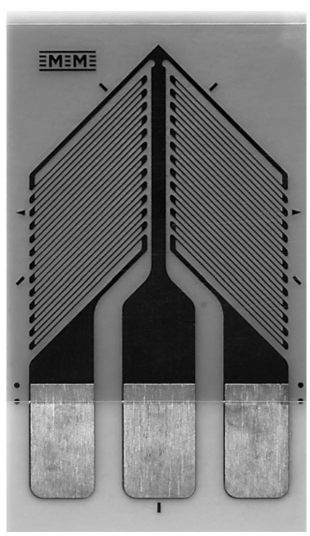


Figure 1: 187UV shear/torque pattern. Two-element 90° rosette for torque and shear-strain measurement. Sections have a common electrical connection.

These were shear/torque rosettes, with each "gage" having 2 separate grid elements oriented at ±45-degrees to the main axis. They had a common electrical connection and were configured in a half bridge for data collection. This bridge configuration counts on the fact of pure torsion, each individual element would measure an equal magnitude/opposite direction strain. The half bridge also allows for an output of 2 times the uni-axial strain or the shear strain directly.

To obtain the torque from this arrangement, shaft diameter and material properties are needed. The shafts were all machined martensitic precipitation-hardening Stainless Steel 17-4 PH. The shaft diameters were 5.510-in, 3.150-in, and 2.559-in for the 36-in, 24-in, and 18-in butterfly valves respectively. The conversion of the shear strain to torque is through the following equations:

$$\gamma = \frac{\tau}{G}$$

where **g** is the shear strain, **t** is the shear stress, and ***G*** is the shear modulus of elasticity of the shaft material. The shear stress in the shaft is a maximum at the surface and is described by:

$$\tau = \frac{TR}{J}$$

where ***T*** is the torque, ***R*** is the shaft radius, and ***J*** is the polar moment of inertia of the shaft. We know that

$$J = \frac{\pi d^4}{32}$$

where ***d*** is the shaft diameter, so substituting and solving for the torque:

$$T = \frac{\gamma \pi R^3 G}{2}$$

The constants ***E*** and ***G*** (the modulus of elasticity also known as Young's modulus and the shear modulus of elasticity, respectively) are related through Poisson's ratio (the ratio of lateral strain to axial strain), resulting in:

$$G = \frac{E}{2(1+\nu)}$$

where ***n*** is Poisson's ratio. These are material-dependant properties that can be looked up and for the shaft's particular stainless steel alloy, ***E***=$28.6 \text{x} 10^6$ lb/in^2 and Poisson's ratio is 0.31. Making this final substitution gives:

$$T = \frac{\gamma \pi E R^3}{4(1+\nu)}$$

In order to have the torque output in ft-lbs, it is necessary to divide the above result by 12.

The gages were wired into a Vishay D4 Data Acquisition Conditioner box (figure 2) via shielded Ethernet cables. The D4 is controlled and communicates with a laptop computer via the USB interface. A standard software package is supplied with the D4 where gage wiring configuration and gage factor are input and frequency of collection and storage parameters are input. The gage factor for all gages used in this testing was 2.075 per manufacturer's specification sheets. The data rate was selected as 8 Hz (maximum for this device) and each test condition was stored in a separate ASCII text file. These text files were imported into a spreadsheet and the shear strains converted to torque using the final equation presented previously.

Figure 2: D4 data acquisition conditioning box.

Testing and Results

A table of the test conditions (Table 1) as well as a second table showing maximum torque values (Table 2) detail the work performed.

Table 1: Summary of test conditions.

Test No.	Date	Time	Unit No.	Valve	Test condition	Bridge config.
1	11/8/2011	8:18	6	Discharge	Balanced/drained/seated/motor-operator	Full
2	11/8/2011	8:33	6	Guard	Unbalanced/seated/hand wheel	Full
3	11/8/2011	9:37	6	Discharge	Unbalanced/pump/seated/motor-operator	Full
4	11/8/2011	10:11	6	Discharge	Unbalanced/pump/off seat/motor operator	Full
5	11/8/2011	11:15	6	Discharge	Unbalanced/pump/check closed/motor operator	Full
6	11/8/2011	14:01	3	Guard	Unbalanced/seated/check open/hand wheel	Half
7	11/8/2011	14:15	3	Guard	Balanced/seated/check closed/hand wheel	Half
8	11/8/2011	14:29	3	Discharge	Balanced/seated/motor operator	Half
9	11/8/2011	14:33	3	Discharge	Unbalanced/pump/seated/motor operator	Half
10	11/8/2011	14:44	1	Guard	Balanced/seated/motor-operator	Half
11	11/8/2011	14:54	1	Discharge	Balanced/seated/motor operator	Half
12	11/8/2011	14:57	1	Discharge	Unbalanced/pump/seated/motor operator	Half
13	11/8/2011	16:18	6	Discharge	Unbalanced/pump/seated/motor operator/hand wheel	Half
14	11/8/2011	16:23	6	Discharge	Balanced/seated/motor operator	Half
15	11/8/2011	16:28	6	Discharge	Balanced/seated/motor operator	Half
16	11/8/2011	16:30	6	Guard	Unbalanced/seated/hank wheel	Half
17	11/8/2011	16:37	6	Discharge	Unbalanced/pump/seated/motor operator	Half
18	11/8/2011	16:45	6	Discharge	Unbalanced/seated/motor operator	Half
19	11/9/2011	8:20	5	Discharge	Unbalanced/pump/seated/motor operator	Half
20	11/9/2011	8:57	6	Discharge	Balanced/pump/seated/motor operator	Half
21	11/9/2011	9:05	6	Discharge	Unbalanced/pump/seated/motor operator	Half

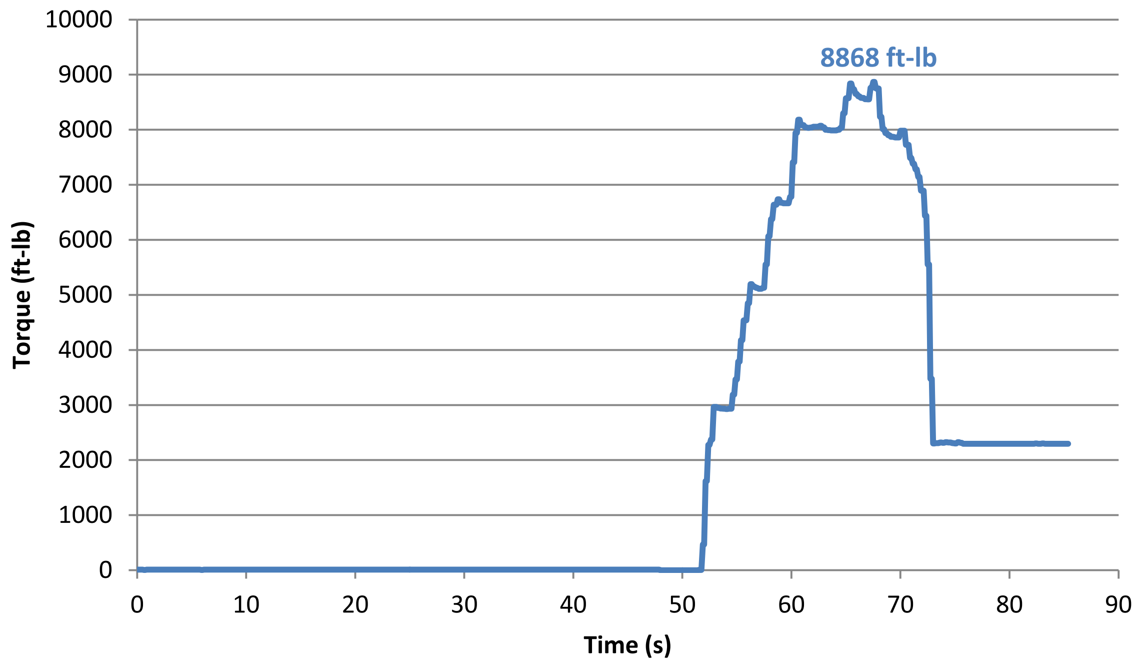
Table 2: Maximum torques recorded and report of valve performance.

Test No.	Unit No.	Valve	Maximum Torque (ft-lb)	Successfully opened
1	6	Discharge	n/a wiring error*	No – torque limit reached
2	6	Guard	n/a wiring error*	No – handwheel
3	6	Discharge	n/a wiring error*	No-torque limit + handwheel
4	6	Discharge	n/a wiring error*	No-torque limit/Yes handwheel
5	6	Discharge	n/a wiring error*	Yes
6	3	Guard	8868	Yes
7	3	Guard	6292	Yes
8	3	Discharge	1948	Yes
9	3	Discharge	7743	Yes
10	1	Guard	4576(motor-torque limit) 5373(hand wheel)	No Yes
11	1	Discharge	198	Yes
12	1	Discharge	2245	Yes
13	6	Discharge	19780/20198(torque limit) 20348/20796(hand wheel)	No Yes
14	6	Discharge	6872/5886	Yes
15	6	Discharge	1912/1554	Yes
16	6	Guard	45446/42028	No – crack in casing
17	6	Discharge	18764/17091	Yes
18	6	Discharge	20826/19720 (torque limit)	No
19	5	Discharge	26951	Yes – with some effort to not allow limit to be hit
20	6	Discharge	6748/6870 then 19023/19451	Yes
21	6	Discharge	5687/5716	Yes

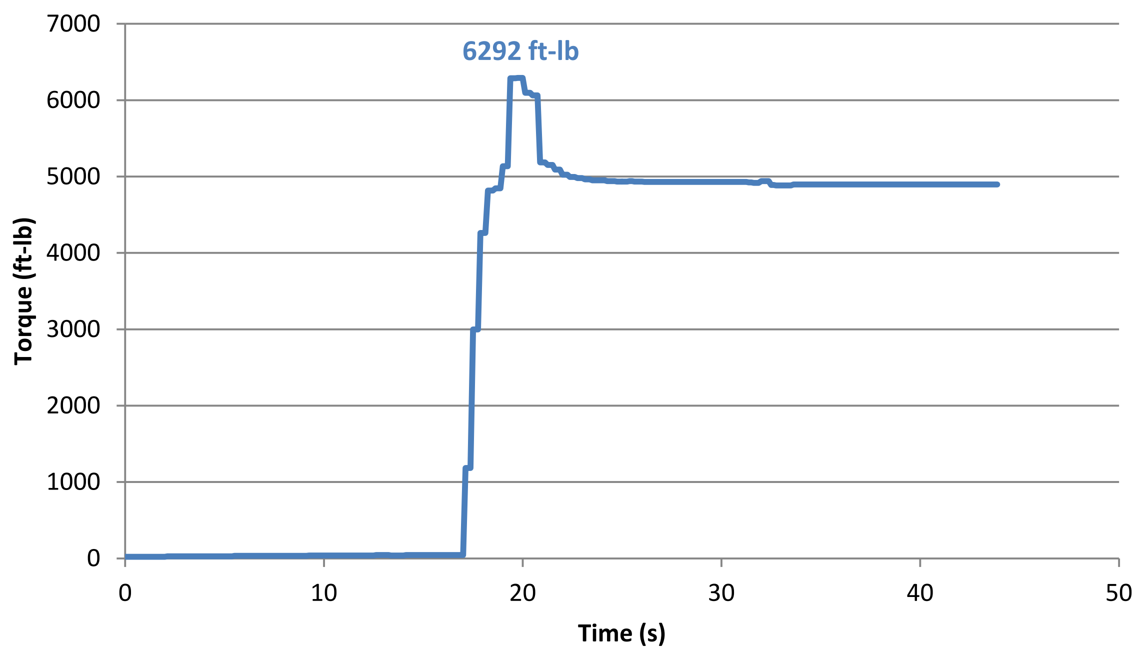
*a misinterpretation of the wiring schematic for the proper full-bridge configuration resulted in a null bridge output, showing only indication of gage misalignment. No torque data could be deduced from this arrangement.

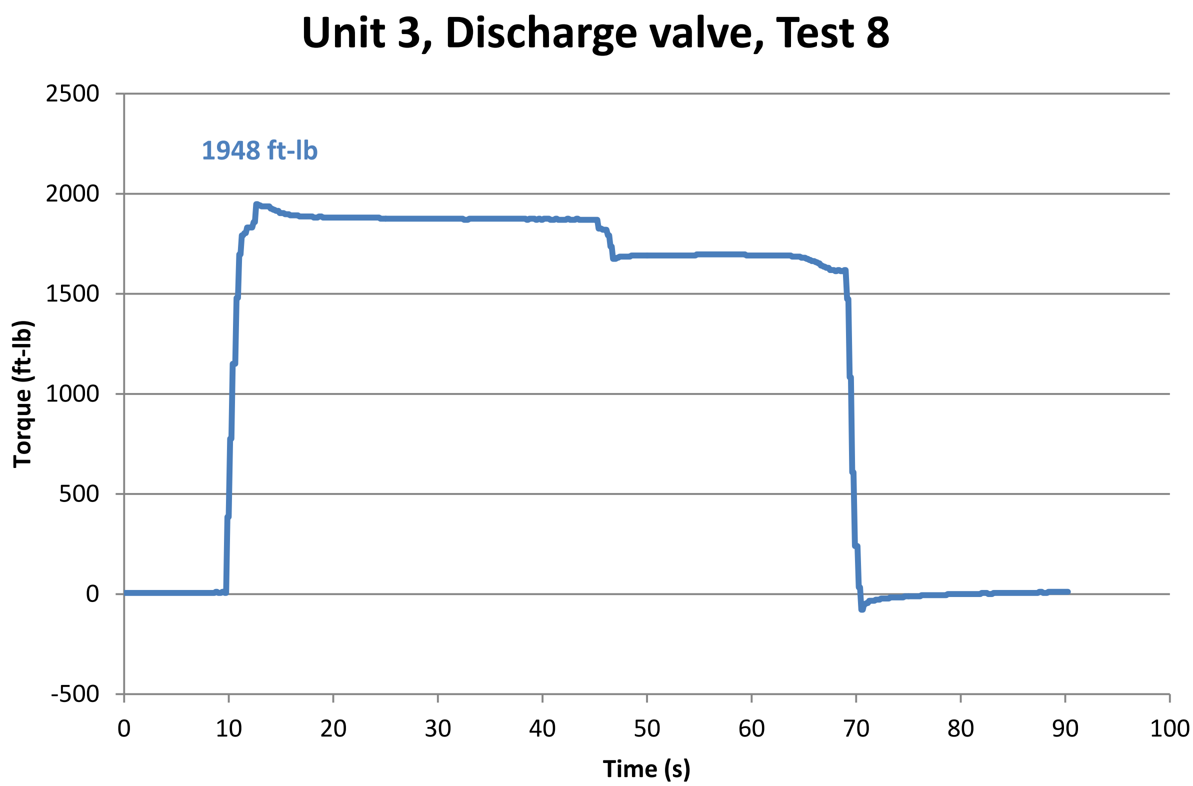
Complete results are shown in the following time series plots of torque for each test performed. The tests on Unit 6 show outputs of 2 gage installations, roughly on opposite sides of the shaft from one another. Differences in the values of shear strain (i.e. torque) are likely caused by slight misalignments from the central axis of the shaft. The plots are titled corresponding to the test number from Table 1.

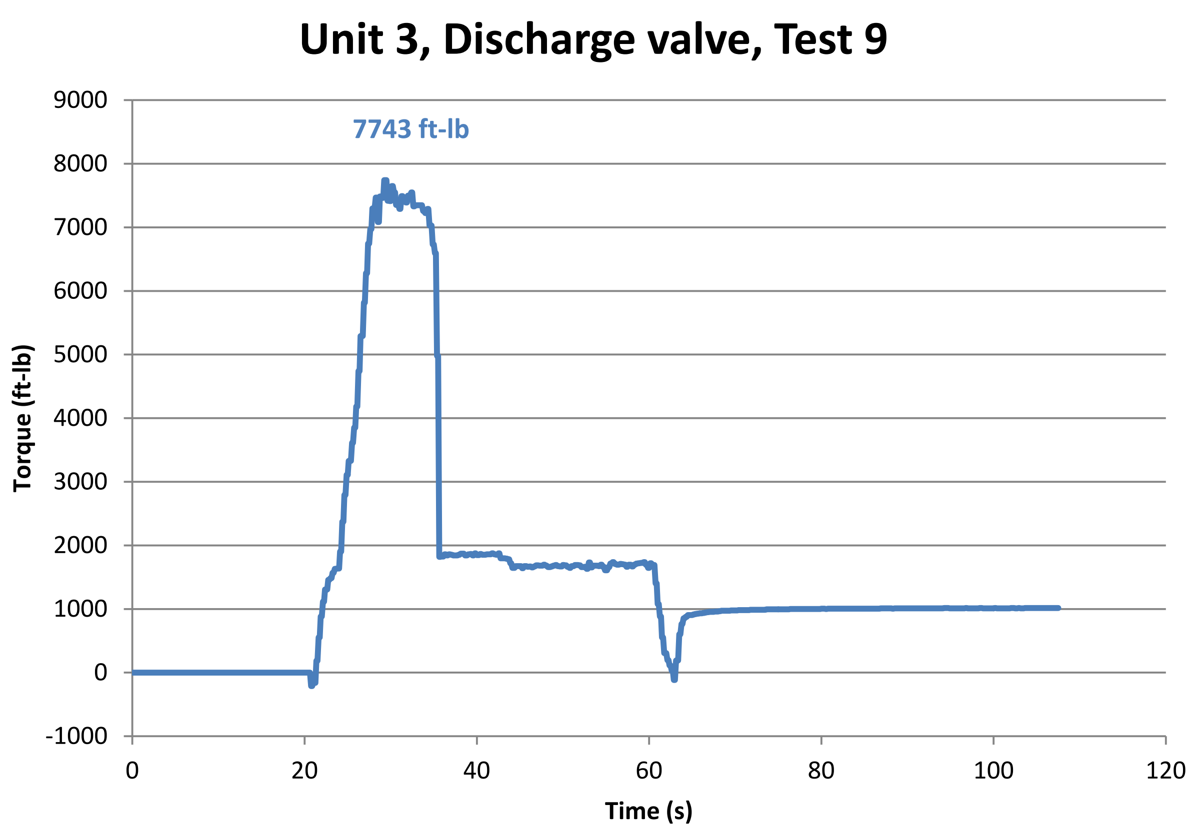
Unit No. 3, Guard valve, Test 6

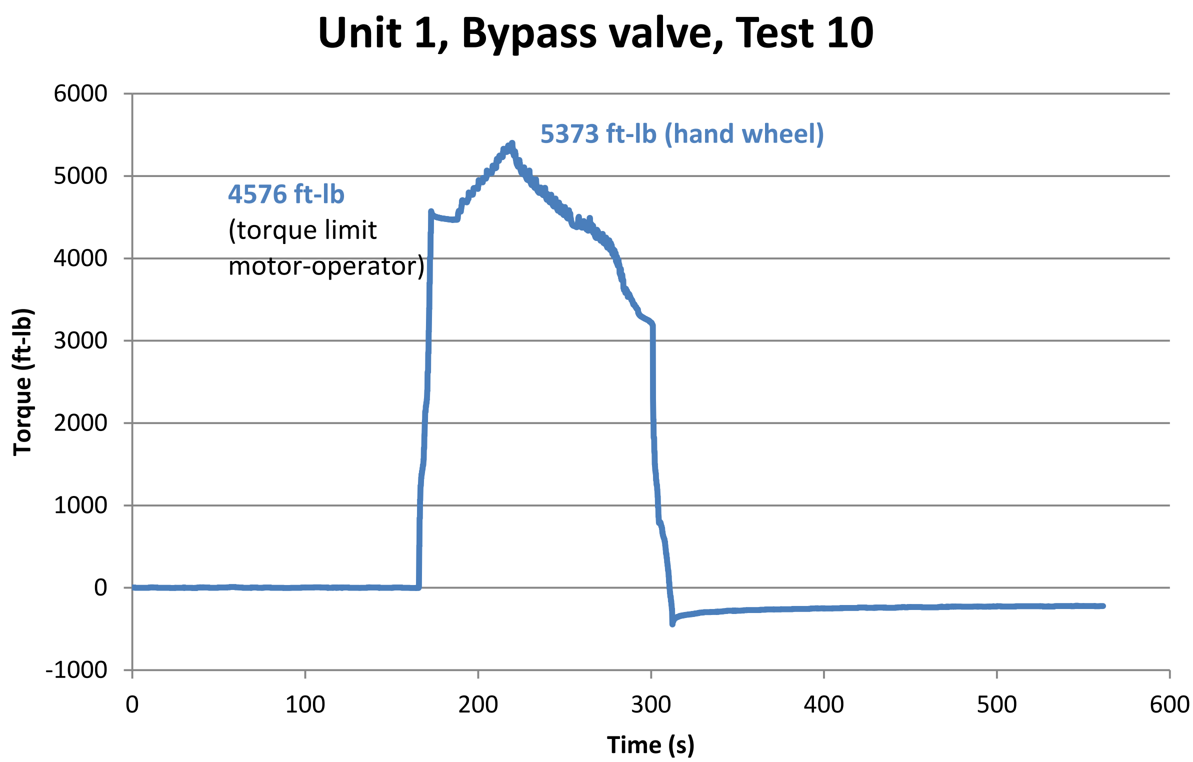


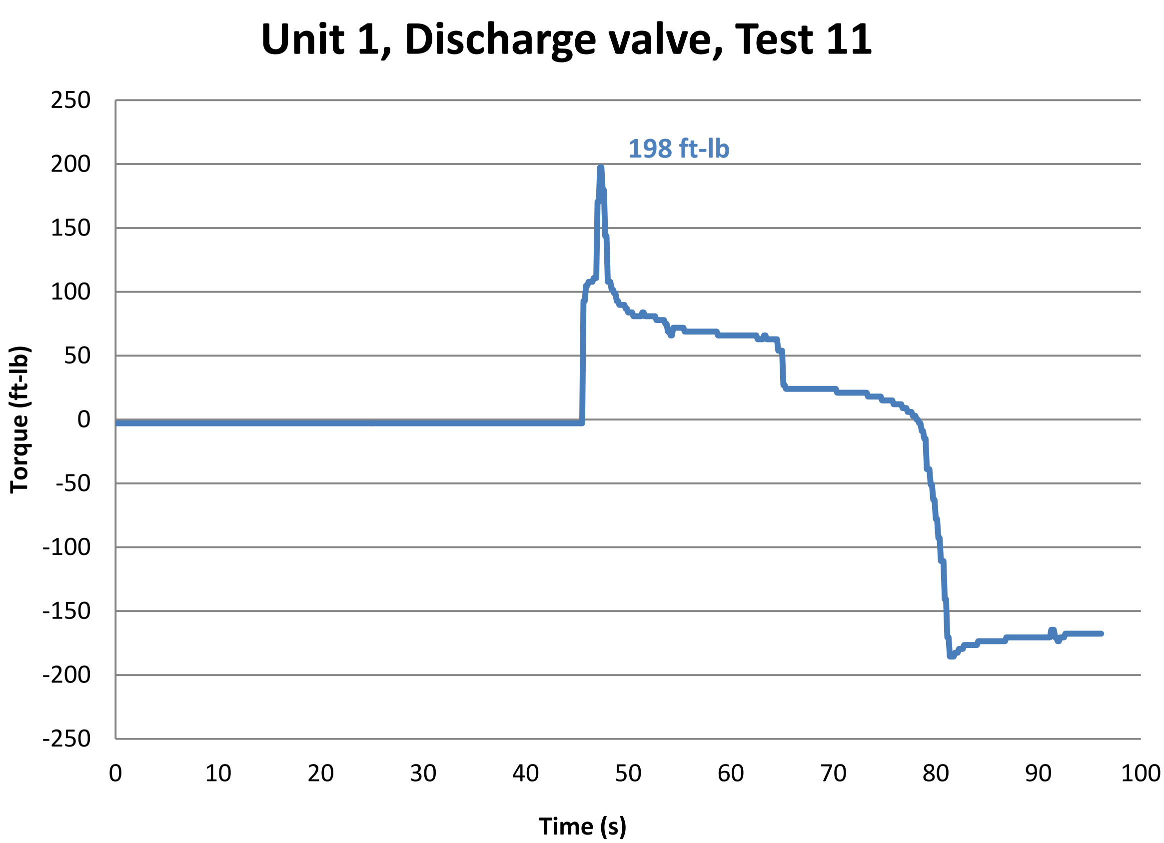
Unit No. 3, Guard valve, Test 7

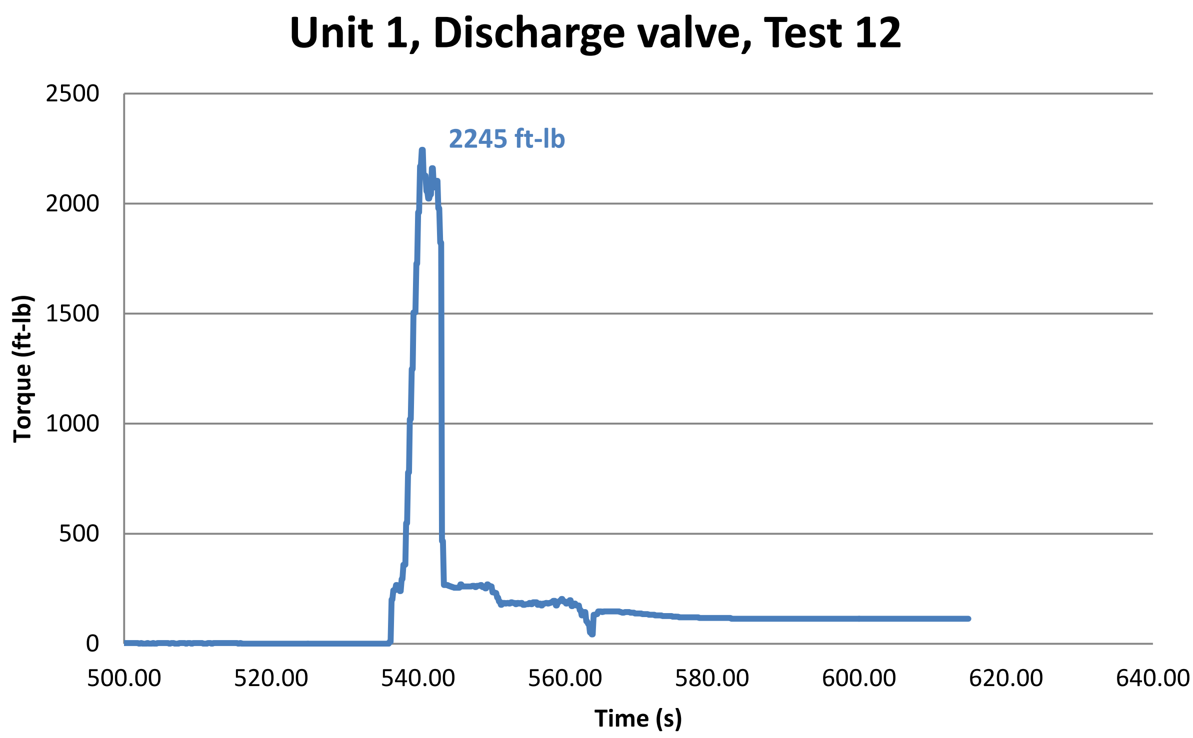


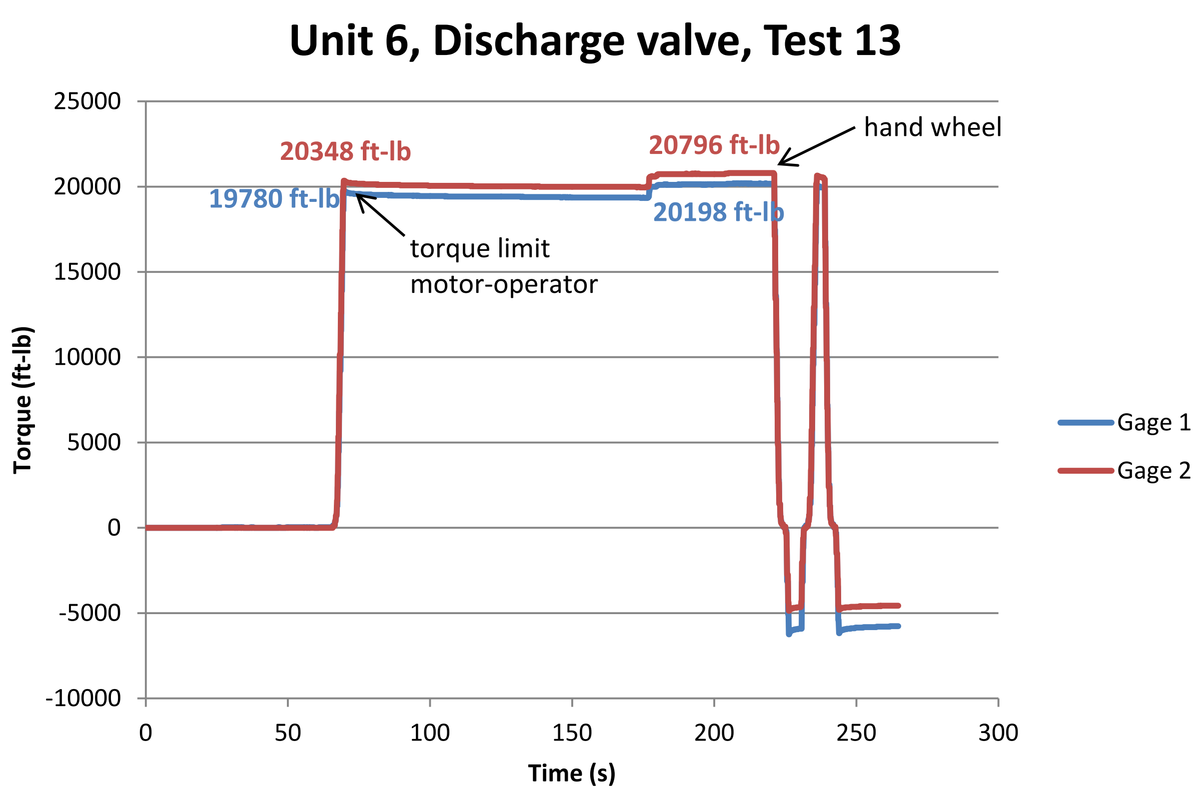

Unit 3, Discharge valve, Test 8
1948 ft-lb
Torque (ft-lb)
2500
2000
1500
1000
500
0
-500
0
10
20
30
40
50
60
70
80
90
100
Time (s)

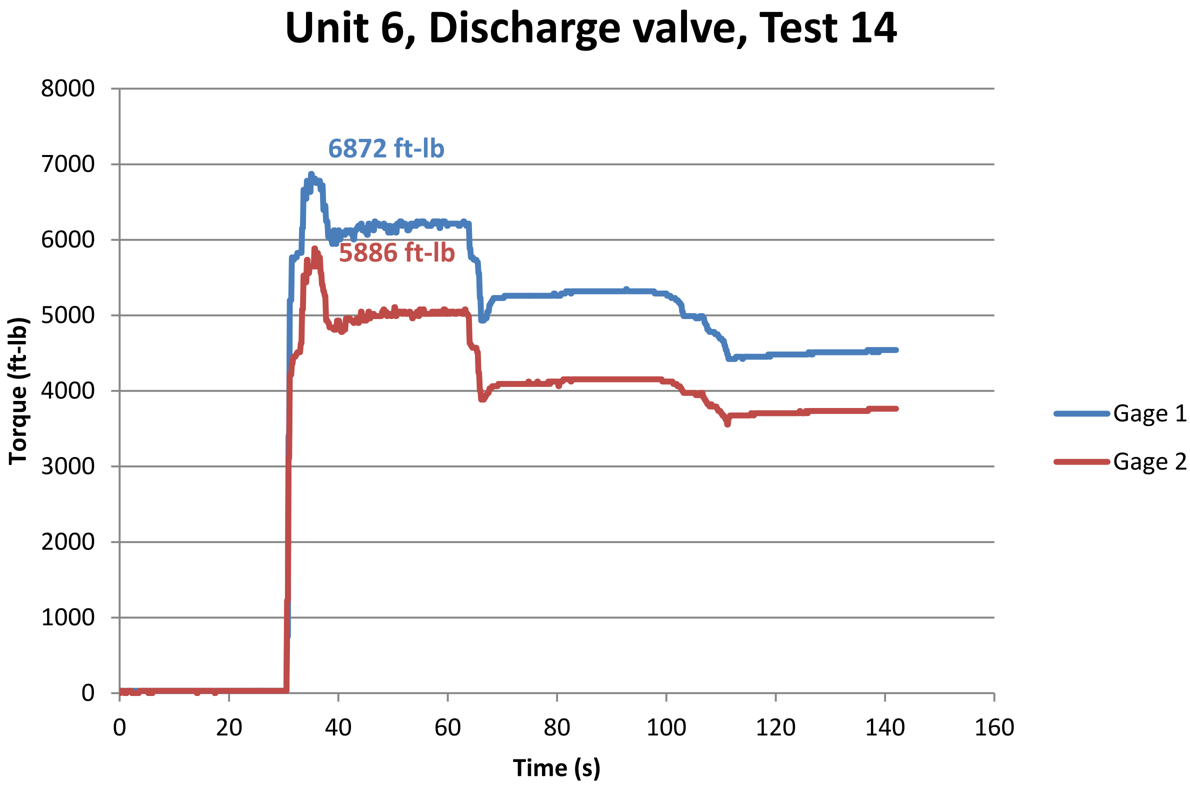

Unit 3, Discharge valve, Test 9
7743 ft-lb
Torque (ft-lb)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
20
40
60
80
100
120
Time (s)

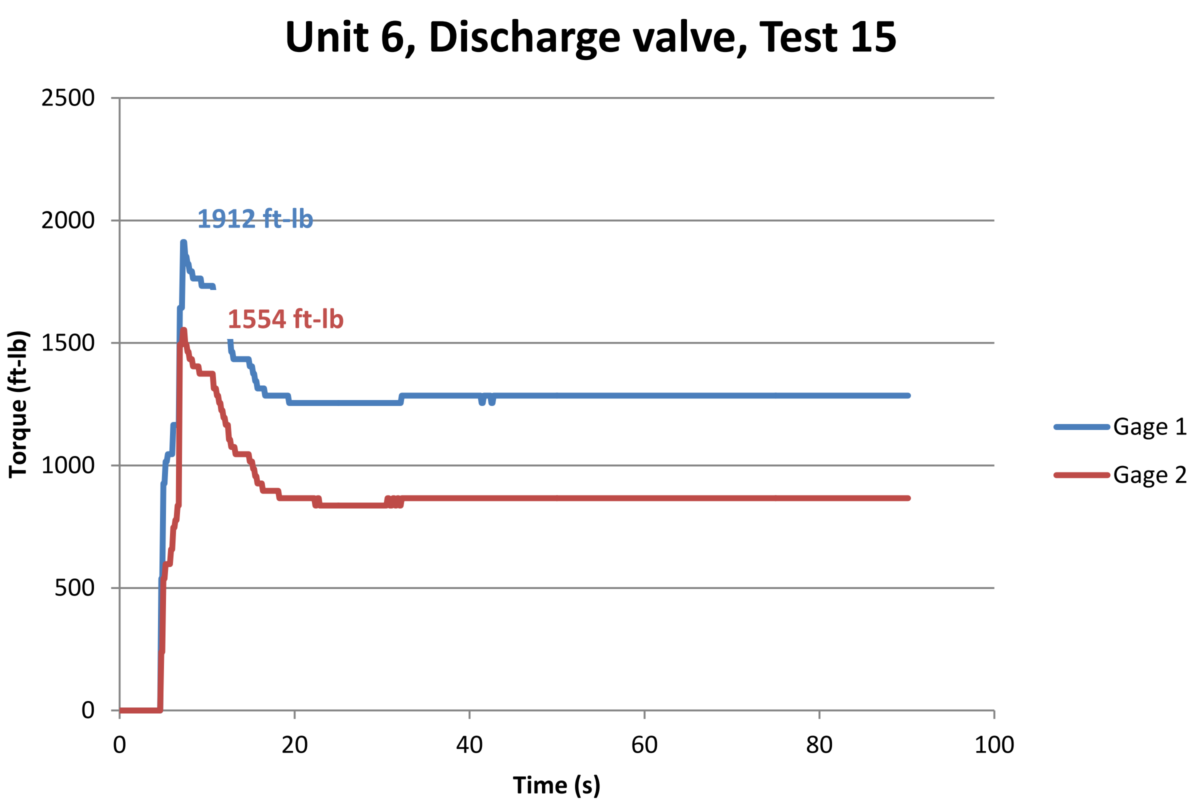

Unit 1, Bypass valve, Test 10
5373 ft-lb (hand wheel)
4576 ft-lb
(torque limit
motor-operator)
Torque (ft-lb)
6000
5000
4000
3000
2000
1000
0
-1000
0
100
200
300
400
500
600
Time (s)

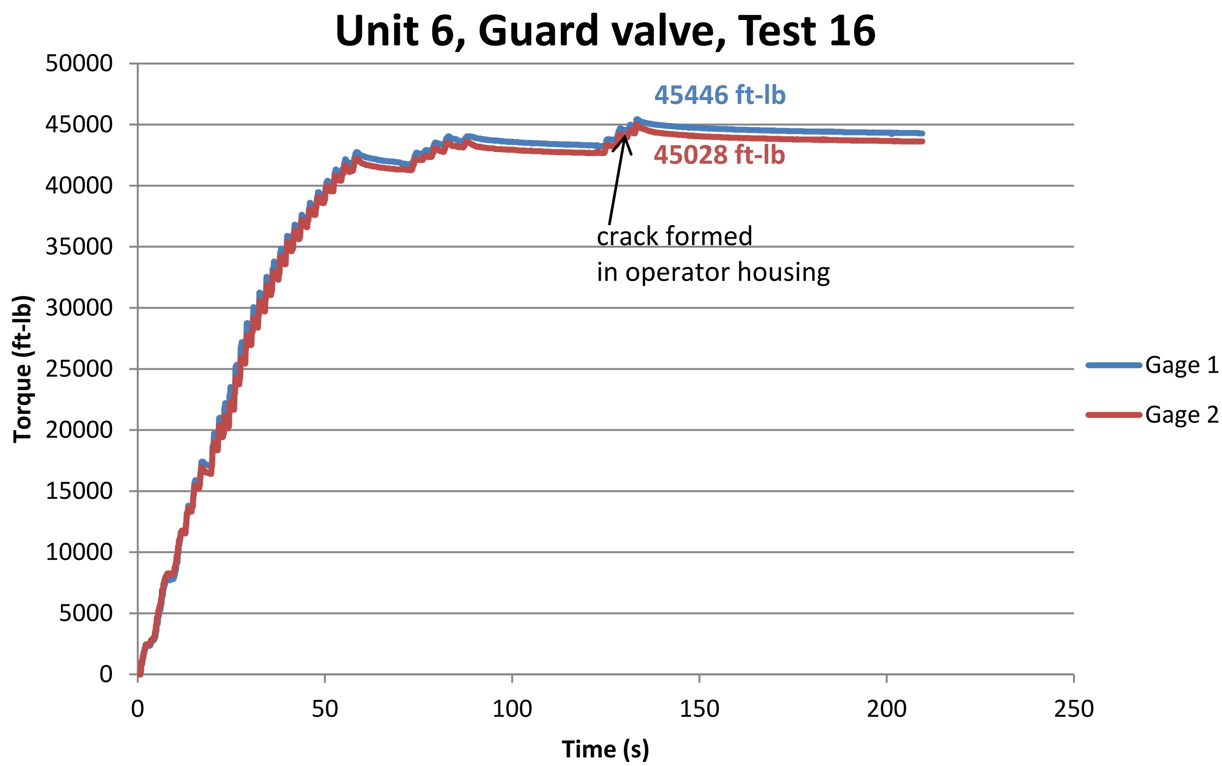

Unit 1, Discharge valve, Test 11
198 ft-lb
Torque (ft-lb)
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
10
20
30
40
50
60
70
80
90
100
Time (s)

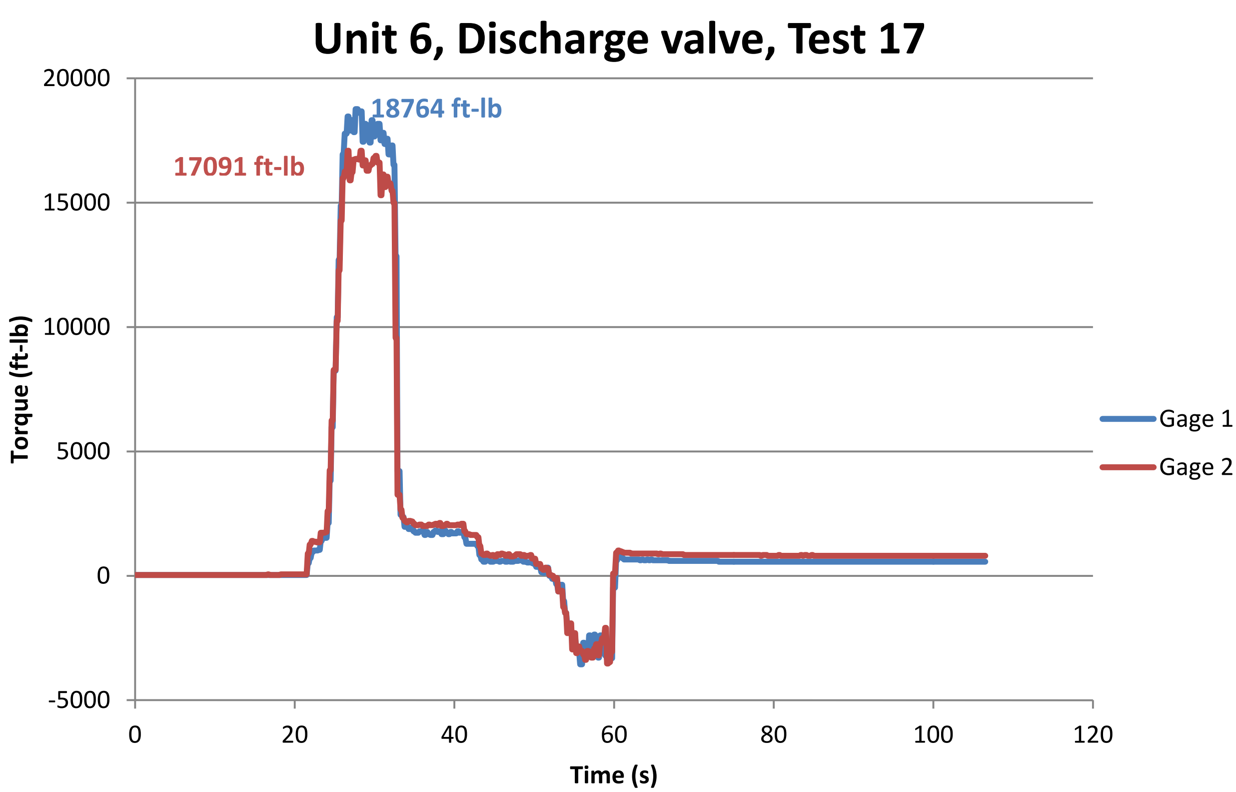

Unit 1, Discharge valve, Test 12
2245 ft-lb
Torque (ft-lb)
2500
2000
1500
1000
500
0
500.00
520.00
540.00
560.00
580.00
600.00
620.00
640.00
Time (s)

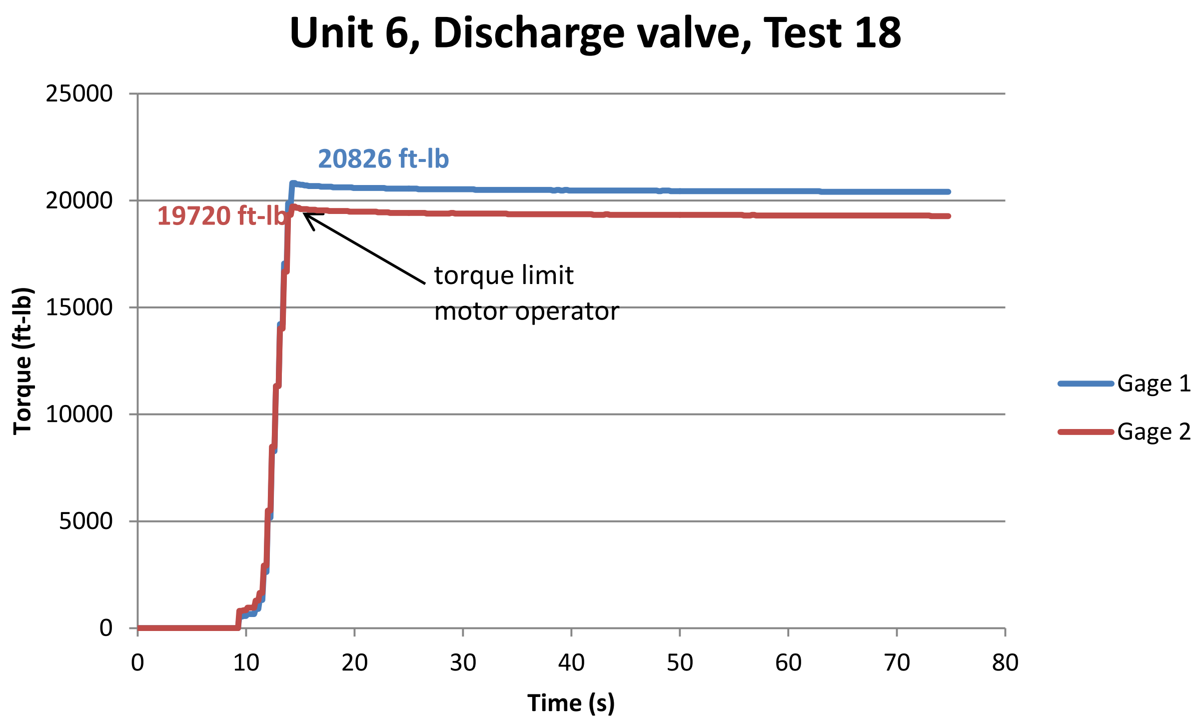

Unit 6, Discharge valve, Test 13
20348 ft-lb
19780 ft-lb
20796 ft-lb
20198 ft-lb
hand wheel
torque limit
motor-operator
Torque (ft-lb)
25000
20000
15000
10000
5000
0
-5000
-10000
0
50
100
150
200
250
300
Time (s)
Gage 1
Gage 2

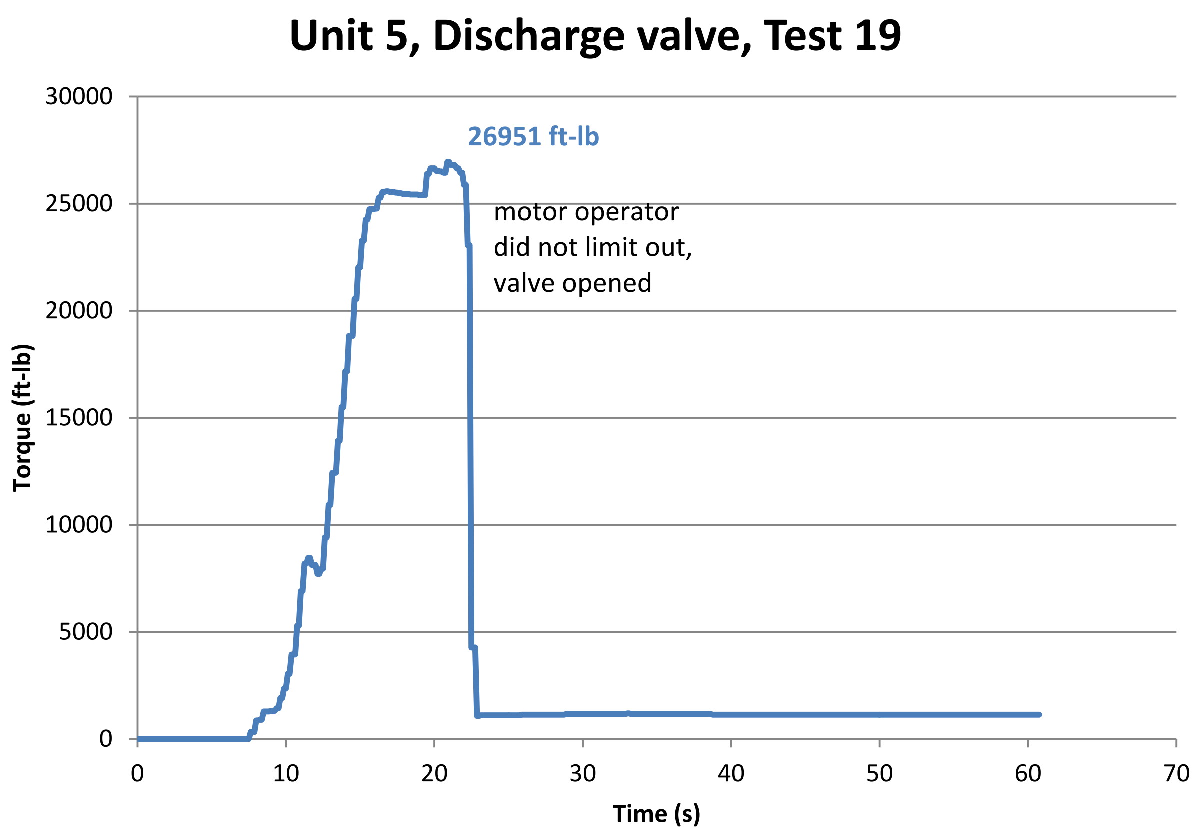

Unit 6, Discharge valve, Test 14
6872 ft-lb
5886 ft-lb
Torque (ft-lb)
Time (s)
Gage 1
Gage 2
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
120
140
160

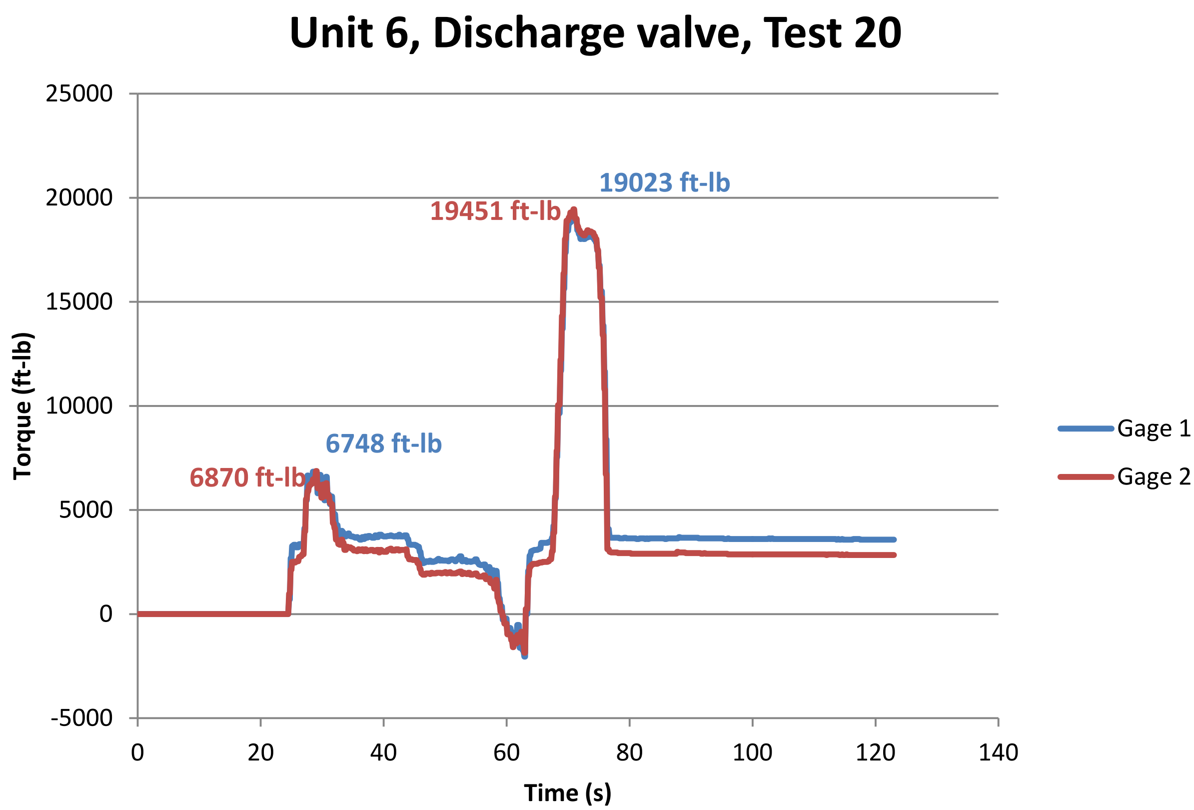

Unit 6, Discharge valve, Test 15
1912 ft-lb
1554 ft-lb
Torque (ft-lb)
Time (s)
Gage 1
Gage 2
2500
2000
1500
1000
500
0
0
20
40
60
80
100

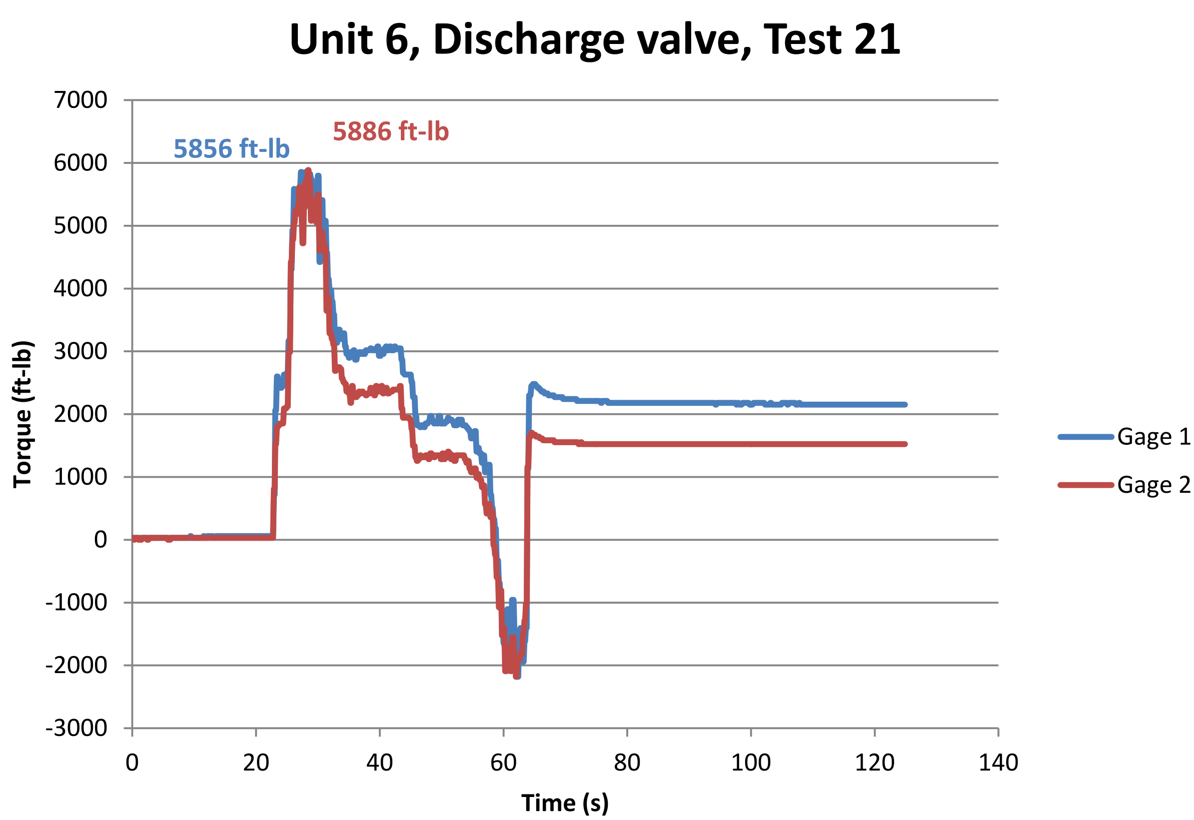

Unit 6, Guard valve, Test 16
45446 ft-lb
45028 ft-lb
crack formed
in operator housing
Torque (ft-lb)
Time (s)
Gage 1
Gage 2
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
50
100
150
200
250


Unit 6, Discharge valve, Test 17
18764 ft-lb
17091 ft-lb
Torque (ft-lb)
Time (s)
Gage 1
Gage 2
20000
15000
10000
5000
0
-5000
0
20
40
60
80
100
120


Unit 6, Discharge valve, Test 18
25000
20000
15000
10000
5000
0
Torque (ft-lb)
20826 ft-lb
19720 ft-lb
torque limit
motor operator
0
10
20
30
40
50
60
70
80
Time (s)
Gage 1
Gage 2


Unit 5, Discharge valve, Test 19
30000
25000
20000
15000
10000
5000
0
Torque (ft-lb)
26951 ft-lb
motor operator
did not limit out,
valve opened
0
10
20
30
40
50
60
70
Time (s)


Unit 6, Discharge valve, Test 20
Torque (ft-lb)
Time (s)
19023 ft-lb
19451 ft-lb
6748 ft-lb
6870 ft-lb
Gage 1
Gage 2
25000
20000
15000
10000
5000
0
-5000
0
20
40
60
80
100
120
140


Unit 6, Discharge valve, Test 21
Torque (ft-lb)
Time (s)
5856 ft-lb
5886 ft-lb
Gage 1
Gage 2
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
0
20
40
60
80
100
120
140

Conclusions

Test data collected at Durango Pumping Plant on November 7-9, 2011 has been included in this report. The main focus of the testing was to measure opening torques on several butterfly valves within the plant. The valve sizes tested were, 36-in, 24-in, and 18-in. Both motor-operated and manually actuated valves were tested. In general, valves were successfully opened; however, during several tests, torque limit switches were tripped. Several cases when the motor-operator had tripped; the valves were able to be opened with the hand wheel. This did not occur on all occasions, and in particular the manually actuated guard valve on Unit 6 could not be opened. The hand wheel on this valve was used to apply more than 3.5 times the manufacturer's specified opening torque value, with the result being a cracked operator casing.

Specific test conditions could not be clearly identified due to the lack of pressure differential measurements across the valves. Unbalanced head conditions were likely varied between fully unbalanced and partial differentials due to leakage, check valve position, or other operational factors. At the conclusion of the testing, the gages were left in position and the leads secured in the event that additional testing may be requested.