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August 25, 2011

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Mr. Patrick Fahn
North Dakota Public Service Commission
600 E. Boulevard, Dept. 408
Bismarck, ND 58505-0480

VIA ELECTRONIC DELIVERY
AND OVERNIGHT MAIL

Dear Mr. Fahn:

In response to your request on August 15, 2011, TC Oil Pipeline Operations Inc. submits the enclosed information, which summarizes of our submittals to the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) as required under the Amended Corrective Action Order (CAO) issued on June 23, 2011. As Ms. Sacco requested in her May 17 email, we are providing documents that do not require FOIA protection.

If you have any questions regarding the enclosed report or in general regarding the progress made to date on the failure investigation and remediation, I would be happy to discuss this with you. In addition, as requested, representatives from our company will attend the September 21, 2011 commission meeting and make a brief presentation at that time.

Sincerely,

Ken Crowl

Ken Crowl
Manager, U.S. Regulatory Compliance

739 PU-06-421 Filed: 8/26/2011 Pages: 19
Keystone system restart plan and executive summary of submittals to PHMSA

TransCanada Keystone Pipeline, LP

Ken Crowl

KEYSTONE SYSTEM RESTART PLAN

- Following Ludden, ND Pump Station Thermal Relief Valve Nipple Failure and Severance, KS Pump Station Discharge Pressure Transmitter Nipple Failure Incidents

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June 4, 2011

1 INTRODUCTION

TransCanada operates the Keystone oil pipeline system from Hardisty, Alberta to delivery terminals in Wood River and Patoka, Illinois and Cushing, Oklahoma. On May 7, 2011 the system experienced a reportable oil release of approximately 400 barrels at the Ludden, ND pump station. On May 29, 2011 a second reportable oil release of approximately 10 barrels occurred at the Severance, KS pump station. Neither of these failures had the potential to impact a High Consequence Area (HCA).

In both cases TransCanada's Oil Control Center quickly detected the leaks through advanced monitoring systems, and, immediately responded by isolating the pump stations and shutting down the pipeline. When the Ludden release occurred, TransCanada personnel in the Control Room were already actively responding to the indicators of a leak when a call from a local man was received by the manned notification center. The caller knew who to call because of information he had received through the extensive TransCanada Public Awareness Program.

All leak detection and pipeline isolation equipment functioned as designed. The majority of released oil was contained on-site and off-site environmental impacts were minimal. Clean up efforts were started immediately and finished in less than one week of the initial occurrences.

TransCanada's internal review of oil control system operating records determined that the incidents did not cause, nor were they a result of, any pipeline overpressure events.

TransCanada secured an independent materials testing laboratory to conduct mechanical and metallurgical testing in order to complete a failure analysis of the failed pipe components as part of a comprehensive investigation into the failure. An extensive third party vibration study has been commissioned that will determine the root cause of the operational vibrations being experienced, identify the long term effects of these vibrations and recommend further corrective actions if required.

Improper or defective materials were ruled out as contributing factors of either incident. The source of the leak at the Ludden Pump Station was a 1 – inch X ¾ inch threaded swaged nipple connection on small diameter thermal relief valve piping. This piping was located on the 30" downstream pump station discharge piping in the proximity of the station Pressure Control Valve. Metallurgical analysis of the nipple identified the presence of cracks at the root of the threads believed to be the result of over-torquing of the fitting during installation. High cycle fatigue due to operational vibrations propagated the cracks to failure.

The source of the leak at the Severance Pump Station was a ½ inch diameter nipple at an oil pressure transmitter manifold located on the 30" downstream pump station discharge piping in the proximity of the station pressure control valve. Metallurgical testing has indicated the cause of the failure to be high cycle fatigue due to operational vibrations. No signs of over torquing were observed on the Severance nipple.

To ensure the safe and reliable restart of the pipeline and to prevent recurrence of similar incidents occurring on the Keystone system in the future, TransCanada has made improvements. These include replacements and modifications to the affected components at the Ludden and Severance Pump Stations and all other applicable stations along the entire length of the pipeline. In addition to these improvements, extensive non-destructive tests (i.e. magnetic particle inspections and dye penitent inspections) were performed on station piping connections that were in proximity to the pressure control valve on every like kind pump station to ensure that these connections were not adversely affected by the operational vibrations that contributed to the two nipple failures.

TransCanada used a staged approach to safely restart the Keystone pipeline system which included manned coverage at certain identified stations. Ramping up the flows on the system in stages allowed for a gradual increase in the load on the pipeline system. This conservative approach allowed the system time to gradually warm up, as well as providing an opportunity to confirm the effectiveness of the repairs and assess operational vibration levels prior to proceeding to each subsequent flow rate stage. Additional modifications are planned to further reduce the probability of recurrent incidents.

After the Office of Pipeline Safety's review and approval of the Restart Plan and the corrective actions taken to date, TransCanada commenced restart operations during daylight hours only on Sunday, June 5, 2011.

2 FAILURE CAUSES

The failed materials were secured at site and transferred to a Materials Testing firm located in Houston, Texas, Blade Energy Partners who then prepared failure investigation reports on both failures at the request of TransCanada. The transit information and supporting documents can be found in Appendix G. The primary cause of the failed fittings at the Ludden and Severance pump stations was vibration induced high cycle fatigue, with the Ludden fitting failure being initiated by an over torquing event. The testing did not identify faulty materials. The test reports have been provided to PHMSA and any future updates or revisions will be sent simultaneously to PHMSA and TransCanada by Blade Energy Partners.

The principle source of the vibration at the pump stations has been identified as the control valve located on the discharge piping of each pump station and used to control station output pressure. This pressure control valve (PCV) opens and closes incrementally to reduce throughput and control the station output pressure. TransCanada's investigation and analysis has concluded that the level of vibration from this valve increases as the valve is closed under high flow conditions.

Both the Ludden and Severance pump stations use fixed speed drives that require the utilization of the PCV to ensure that the Maximum Operating Pressure of the pipeline is not exceeded. TransCanada has analyzed the historic use of the PCV at fixed speed stations and has determined it as the primary factor for prioritizing modifications at these fix speed pump stations.

Some Keystone pump stations utilize electric motors which can vary their output speed through the use of a variable frequency drive (VFD). These VFD equipped stations can modulate the station output pressure without the use of the PCV. In these stations the PCV is used very little to reduce pressure and therefore have not created high vibration conditions.

Field operations staff has also reported higher levels of operational vibrations at the fixed speed stations and minimal vibrations at VFD stations. The scope of modifications or replacements was directed by the conclusion that the high operational vibration levels associated with high cycle fatigue were principally present at fixed speed stations. This conclusion is supported by the PCV utilization histograms in Appendix C. Vibration readings will be collected at a representative VFD station during initial startup to verify this conclusion.

TransCanada's has reviewed its station level control systems and concluded that variations in the control system logic are not a contributor to these incidents. The pressure control logic at all VFD stations is the same and the pressure control logic at all PCV only stations is the same. Tuning parameters are the only differences from station to station. Tuning parameters were first established through modeling and then adjusted during initial on site commissioning. Further tuning was performed as line rates increased in January & February of 2011. Most of our fixed speed stations are at software station PLC software version 2.04 with a few sites at 2.05 (we are part way through a release upgrade). We have release notes associated with the changes. The differences are not related to the control valve logic, so from a control valve logic perspective, all sites are the same.

3 EQUIPMENT MODIFICATIONS, REPLACEMENTS AND INSPECTIONS

3.1 The following actions were taken as a result of the Ludden incident at all VFD and fixed speed stations due to the possibility of over torque installation at any site:

- All schedule 80 swage nipples used on the thermal relief valves were replaced with schedule 160 fittings. The schedule 160 fitting is a thicker walled material which helps to minimize the effect of operational vibrations and reduces the susceptibility to over torquing during installation. Instructions were provided to installation crews on how to complete the installation of new nipples to avoid over torque installations.

- Bracing was installed on the thermal relief valve piping assemblies at every VFD and fixed speed station. The bracing minimizes the levels of operational vibrations on the susceptible fitting and other joints on the piping assembly. See Appendix G for the bracing details. The second generation bracing will be installed at those fixed speed pump stations where the first generation bracing does not adequately reduce the vibration levels as determined through ongoing vibration measurement.

3.2 The following actions were taken as a result of the Severance incident:

Relocation of Pressure Transmitters

At all fixed speed stations the three transmitters (PT-201, PT-203, PT-205 in above Figure) located in close proximity to the PCV have been relocated off the 30 inch piping, mounted on a separate support structure and connected via ½ inch stainless tubing. This modification results in the replacement of the nipple which failed as well as significantly reducing the stress on this joint created from the vibration.

Replacement of Nipple

At all fixed speed stations the threaded nipples on the remaining pressure transmitter assemblies in the station (PT101, PT103, PY1001, PT1013, PT1021, PT1023, PT202, PY1031, and PR1033 in the Figure above) will be replaced. This removes the existing nipple that may have suffered fatigue damage in order to ensure continued safe operation until these transmitters can also be off mounted in a similar fashion to the 3 pressure transmitters located on the discharge piping after initial start up. The replacement of these fittings will zero base the fitting from a fatigue cycle perspective. Also field observations confirm that vibration levels are much less the further away the piping is from the PCV location.

NDE Inspections at Fixed Speed Pump Stations

As an added precaution, a select number of welds on small inch branch connections off the discharge piping in proximity to the PCV were NDE inspected for surface breaking features. All of the completed field NDE inspections revealed no evidence of cracking.

Similarly, NDE inspection was also completed on the welded connection on the instrument valve manifold where it connects to the blind flange. Additionally, this welded connection on the manifold associated with the failed fitting was inspected with dye penetrant at the lab as well as sectioned. No cracking or other defects were revealed that would indicate a diminished weakness to the joint.

NDE Inspections at VFD Pumps Prior to that Station Re-Starting

As an added level of precaution it was deemed prudent to perform inspections on a sample of similar nipple fittings from VFD pump stations. Three nipples from VFD stations were removed and inspected and no evidence of cracking was found.

3.3 Summary of Remedial Measures Taken

In addition to the extensive non-destructive testing and ongoing monitoring, the following measures were taken in an abundance of caution to ensure safe operations.
In response to the Ludden incident, all thermal relief valve piping sections were braced and supported at each of Keystone's 47 stations, and every thermal relief valve fitting similar to the one that failed was replaced with a thicker fitting with a higher safety design factor. These modifications and replacements were part of TransCanada's own Corrective Action and Restart Plan and were completed between May 10, 2011 and May 12, 2011. The pipeline was restarted on May 13, 2011.

In response to the Severance failure, 63 pressure transmitters at 21 pump station sites were remounted on standalone supports isolating them from piping vibrations, and nearly 300 pressure transmitter fittings were replaced with new ones. These modifications and replacements were completed between May 31, 2011, and June 4, 2011. The pipeline was restarted on June 5, 2011.

4 PIPELINE SYSTEM RESTART PLAN

4.1 Phased Restart

TransCanada used a staged approach to gradually ramp up flow and increase load on the pipeline system. This staged approach limited the use of PCV to control flows and thereby reduced vibration levels. This approach increased safety and allowed the system time to gradually warm up. This also provided an opportunity to monitor and confirm the effectiveness of the repairs prior to proceeding to each subsequent flow rate. Each stage has a target flow rate and a short term maximum flow rate which will not be exceeded.

In the first stage 4 fixed speed stations were operated in the US with the 4 remaining fixed speed stations coming into operation in Stage 2 and remaining online in stage 3. All operating, fixed speed stations will be manned for a minimum of 8 hrs per day commencing on the first day of restart and for 4 days of stage 3 operations. The purpose for manning only the fixed speed stations is due to the conclusion that operational vibrations of concern are isolated to these types of station configurations. However, the VFD station at Steele City will be operated in all three stages and will be manned to verify these assumptions. While on site the operations personnel monitored for abnormal operating conditions and assisted with gathering vibration related data. This ensured that the equipment modifications implemented to prevent recurrence are effective.

The restart plan provides for verification of stable operation prior to moving to each subsequent flow rate stage, we will achieve stable operation at the target flow rate. Each flow rate stage increase will occur during daylight hours. Status reports will be completed and verified by a corporate officer for each flow rate stage before proceeding to the next stage. A copy of this report will be sent to PHMSA at the successful completion of each stage.

The local emergency response officials were contacted to inform them of the intended restart of the pipeline.

4.2 Vibration Data Gathering During Restart

On -site vibration monitoring is being performed to ensure that the addition of relief valve bracing has been effective and that vibration levels across the fixed speed station piping is assessed. This data gathering is intended to identify any undiagnosed issues associated with elevated vibration conditions and also identify the sources of vibration and any measures that can be taken to further minimize vibration. This will enhance the factor of safety at these locations. The vibration test data has been provided to PHMSA for review.

Vibration data gathering activities:

1. Sites designated for continuous monitoring were selected based on utilization rates, magnitude of pressure differential across the PCV at fixed speed pumps sites and historical baseline data. This analysis led to the selection of the following priority station; Severance, Freeman, and Fort Ransom (in the US) and Lakesend (in Canada). Vibration signatures will be captured when vibration reaches a threshold level. Pressure control valve position will be captured simultaneously.

2. Additionally, all fixed speed pump sites have discrete data gathering performed at each phase of the start-up at numerous, identified, susceptible locations within each station. This will continue until sufficient data is gathered at high through put levels. Escalation set-points will be developed to facilitate prompt and appropriate actions will be taken upon discovery. Discrete data gathering will be completed within 30 days at VFD pump stations once high flows have been reached.

CPF No. 3-2011-5006H – Keystone Pipeline Corrective Action Order
July Monthly Report & Required Submittals Summary

Executive Summary

The following is a summary of the information submitted to PHMSA in accordance with the Corrective Action Order (CAO) issued on June 3, 2011 and amended on June 23, 2011.

The CAO detailed what would be completed prior to a restart of the system and included this information in Items 1, 2, and 3. The restart plan detailed in Item 1 was submitted to PHMSA on June 4, 2011 and was approved the same day. See Attachment A: Keystone Restart Plan. The restart plan included a staged approach to bringing the system online and progressing to the maximum capacity. Stage 1 was completed on June 8, 2011. Stage 2 was completed on June 16, 2011. Stage 3 was completed on June 24, 2011.

Item 2 of the CAO required the completion of repairs at the failure locations and adequate staffing, monitoring, and patrolling of pump stations during the restart process to ensure that no leaks or failures occur at any facility. All activities were completed in accordance with the restart plan provided to PHMSA. Repairs and modifications completed are included in the "Repairs and Modifications" section below.

Item 3 of the CAO required completion of mechanical and metallurgical testing and failure analysis of the failed pipe components including documenting the chain of custody. The results of the mechanical and metallurgical testing confirmed that the failure was not due to the material itself. The ASTM A420 WPL6 is the correct material for the swage nipples, and the results of the examinations confirmed that this material was used. The chemical compositions, mechanical properties and microstructure meet the requirements for ASTM A420 WPL6.

The information required by Item 4 of the CAO included compilation and submittal of data on previous failures of similar small diameter piping and components. After completing the review of all available data on failures on small diameter piping and components as required under Item 4A, no additional pump station components with susceptibility for hazardous liquid leaks or failures were identified. The documents requested by PHMSA in Item 4B were submitted within the timeframe required.

All of the requirements of Item 5 were submitted to PHMSA on July 14, 2011. As required by this Item, TC Oil Pipeline Operations, Inc. reviewed all of the Issue and Incident Tracking (IIT) reports related to oil releases since the first day of operation of Keystone. The analysis indicated that only four of the incidents were related to vibration issues. Three were included in the CAO. The other release was significantly below a reportable quantity. All releases related to the vibration issue will be addressed in the work plan.

Item 6 required a review of the station manning for each of the pump stations. This was completed and submitted to PHMSA within the required timeframe.

The Root Cause Failure Analysis as required by Item 7 in the CAO is in progress and an interim report was sent to PHMSA within the 60 day timeframe required in the CAO. A third party expert was engaged to complete the RCFA following approval by PHMSA on June 14, 2011. They have conducted a rigorous investigation to determine the factors that contributed to the failure. A final report has not yet been received.

The Work Plan required by Item 8 in the CAO will be developed following completion of all studies, analysis and the review of recommendations provided. It is currently anticipated that this item will be completed on time and submitted to PHMSA.

Introduction

TC Oil Pipeline Operations, Inc. operates the Keystone oil pipeline system from Hardisty, Alberta to delivery terminals in Wood River and Patoka, Illinois and Cushing, Oklahoma. On May 7, 2011 the system experienced a reportable oil release of approximately 400 barrels at the Ludden, ND pump station. On May 29, 2011 a second reportable oil release of approximately 10 barrels occurred at the Severance, KS pump station. Improper or defective materials were ruled out as contributing factors of either incident.

The source of the leak at the Ludden Pump Station was a 1 – inch X ¾ inch threaded swaged nipple connection on small diameter thermal relief valve piping. This piping was located on the 30" downstream pump station discharge piping in the proximity of the station pressure control valve. Metallurgical analysis of the nipple identified the presence of cracks at the root of the threads believed to be the result of over torquing of the fitting during installation. High cycle fatigue due to operational vibrations propagated the cracks to failure.

The source of the leak at the Severance Pump Station was a ½ inch diameter nipple at an oil pressure transmitter manifold located on the 30" downstream pump station discharge piping in the proximity of the station pressure control valve. Metallurgical testing has indicated the cause of the failure to be high cycle fatigue due to operational vibrations. No signs of over torquing were observed on the Severance nipple.

TC Oil Pipeline Operations, Inc. used a staged approach to safely restart the Keystone pipeline system which included manned coverage at certain identified

stations. Ramping up the flows on the system in stages allowed for a gradual increase in the load on the pipeline system. This conservative approach allowed the system time to gradually warm up, as well as provided an opportunity to confirm the effectiveness of the repairs and assess operational vibration levels prior to proceeding to each subsequent flow rate stage.
An extensive third party vibration study has been commissioned that will determine the root cause of the operational vibrations being experienced and recommend further corrective actions if required.

Vibration Testing and Data

Philosophy and Methodology

Vibration monitoring occurred daily during the start up phases according to the Start up plan filed with PHMSA. Two qualified consultants in piping vibration were used to monitor Ft. Ransom, Freeman, and Severance. A Vibration Engineer was on site and was responsible for reviewing the findings at these sites. Southwest Research Institute (SWRI) and the onsite consultants were interpreted test results. The remainder of the fixed speed sites was monitored by where discrete data was taken with hand held data collectors. A dedicated engineering team was put in place for the duration of the startup period to provide support and assess measurements. Vibration readings were sent in daily for evaluation and readings of significance were escalated to Engineering for assessment.

To ensure a conservative approach in assessing observed piping and component vibration levels in the field during startup and subsequent pipeline operations ASME OM-S/G-2007 Standard & Guidelines for Operation & Maintenance of Nuclear Power Plants, Part 3, particularly sections 5.1.1.5.1 & 5.1.2.4 were utilized to set the screening criteria.

The initial action level was set conservatively at an overall vibration level of 40 mm/sec Pk. This vibration level corresponds to the maximum acceptable sustained vibration level of piping systems at 30 Hz. The frequency was initially chosen as a dominant frequency of the prime mover and would represent a lower bound of expected frequency response of significance.

Once the pipeline was operational, subsequent testing data was utilized to indicate if one or more frequencies associated with Pressure Control Valve (PCV) position should be considered to set the screening criteria. Natural frequencies were tested at various attachments and found to be in the range of 30 – 65 Hz. The field screening criteria was left at the conservative level of 40 mm/s pk overall based on 30 Hz. A throttling test conducted at the Severance station at a flow of ~2800 m3/hr and a PCV position of 35% open that demonstrates the broadband energy encountered.

Data was collected during the startup activities in accordance with the re-start plan. Continuous monitoring data captured at Ft. Ransom, Freeman, and Severance was utilized to determine common system response to varying system conditions in order to validate other field data or initiate additional testing at other stations. SWRI was present at a number of sites early in the startup to review the testing process and discuss some of the findings.

Field readings found above the screening level were initially logged as an issue and additional spectral data was obtained where and when appropriate utilizing multi-channel equipment or information was inferred from the continuously monitored sites. Further assessment was completed if field screening criteria were exceeded using the EDI/SWRI screening piping vibration chart.
The spectral, relative motion and continuous monitoring data was then used to determine appropriate mitigation measures for the affected component, such as:

- off-mount the component,
- brace/dampen the component,
- remove the component from service, or
- Install a newly designed component.

A combination of assessment and mitigation measures were assessed and implemented in a manner to allow for safe, continued operation of the Pipeline. Collected information was reviewed to determine site specific and possible systemic issues that would require immediate action. FEA analysis was used as required to assess changes or determine safe operating limits. SWRI, Stress Engineering were consulted as required.

Description of Testing

As communicated in the approved Start Up plan, TC Oil Pipeline Operations, Inc. began operating the pipeline in a staged manner to allow for data collection and observation of equipment. The phases of pipeline operation and testing sites are indicated in the matrix below.

In order to collect data for assessment that would be representative of worst case vibration scenarios, vibration measurements were carried out at the fixed speed stations under normal operating conditions and tests were conducted under simulated conditions (pinch tests) of high rates of energy dissipation across the Pressure Control Valve.

Pipeline Restart Station Test Plan					
Station	VFD/FS	Stage I	Stage II	Stage III	Post Stage III
		June 5-8	June 9-15	June 16-22	Prior to July 15
		2250 m3/hr	2850 m3/hr	3300 m3/hr	Various
Endinburg	V				Discrete
Niagara	V				Discrete

Luverne	V				Discrete
Fort Ransom	F	Continuous	- Continuous - Pinch Test	- Continuous - Pinch Test	
Ludden	F	Daily Discrete	- Daily Discrete - Pinch Test	- Daily Discrete - Pinch Test	
Ferney	F	Daily Discrete	- Daily Discrete - Pinch Test	- Daily Discrete - Pinch Test	
Carpenter	V				
Roswell	F	Daily Discrete	- Daily Discrete - Pinch Test	- Daily Discrete - Pinch Test	
Freeman	F	Continuous	- Continuous - Pinch Test	- Continuous - Pinch Test	
Hartington	V				Discrete
Stanton	V				Discrete
David City	V				Discrete
Willber	V				Discrete
Steele City	V	Daily Discrete	Daily Discrete	Daily Discrete	Discrete
Seneca	F	Daily Discrete	Daily Discrete	- Daily Discrete - Pinch Test	
Severance	F	Continuous	- Continuous - Pinch Test	- Continuous - Pinch Test	
Turney	F	Daily Discrete	Daily Discrete	Daily Discrete - Pinch Test	
Tina	V				Discrete
Salisbury	V				Discrete
Centralia	V				Discrete
Middletown	V				Discrete
St Paul	V				Discrete
Hartford	V				Discrete
Pierron	V				Discrete

Phase I Operations (June 5 to June 8, 2011)

Operations at the Phase I flow rates revealed that Pump Pressure Transmitters had varying degrees of vibration that could not immediately be correlated to specific operating scenarios.

Given that a number of unit pressure transmitters showed vibration that exceeded the field screen criteria and that Roswell nipple leak revealed that the failure mechanism was fatigue of a threaded nipple between the manifold and the pressure transmitter, the decision was made to implement a program to off-mount the Pump Pressure Transmitters from their respective manifold valves, thereby eliminating the risk of fatigue failure in a potentially high stress area. Given that the vibrations were within allowable limits at the predominant frequency, and these nipples were replaced with new prior to start up, operations moved to Phase II flows for further data collection.

Phase II Operations (June 8 to June 16, 2011) (NTD confirm dates)

At Phase II flow rates data was taken utilizing normal station configurations for the targeted flows, and under conditions with the Pressure Control Valve in a throttled position to simulate a worst case scenario.

To simulate worst case conditions a "pinch" test was performed initially at all continuously monitored sites (June 14) and two discrete monitored sites.

Under high PCV throttle conditions Station Pressure Transmitters (PT-201, PT-202, PT-203), Pump Unit Pressure Transmitters (PT-10X1, PT-10X3), Unit Expansion Loop High Point Vents, and Pressure Safety Valve assemblies (PSV-307) responded to the broadband energy produced by throttling operations to varying degrees at each site, resulting in a number of components exceeding the screening criteria. Data was reviewed and analyzed prior to increasing to Phase III flow rates as explained below on a component basis.

Pressure Safety Valve Assembly

Vibration testing of the PSV piping at sites indicated the need to tune the recently installed bracing of the Pressure Safety Valve assembly on a site by site basis to best dampen the response to Pressure Control Valve induced vibration. Crews had been fielded at the beginning of June to verify the adequacy of Pressure Safety Valve bracing across the Pipe System. Upon discovery of vibration levels above the screening criteria, the Field Crews were dispatched to complete the work at the Fixed Speed sites as the priority. Tuning of the Pressure Control Valve bracing resulted in much improved response. Additionally, for any sites with PSV vibration values that exceeded the screening criteria, spectral data was reviewed to determine if peak energy at the dominant frequencies exceeded accepted industry standards. All vibration was found to be within limits.

Pressure Transmitters

Pinch testing at the fixed speed sites resulted in a number of pressure transmitters exceeding the field screening criteria. Discussions with the Field revealed that personnel were taking data at the top of the pressure transmitter valve manifold as a substitution for the pressure transmitter which had been off-mounted. Vibration readings at the fixed speed sites indicated there are commonly elevated levels of vibration at the first and last pump suction and discharge pressure transmitters. A review of data also indicated that the last pump pressure transmitters are heavily influenced by the pressure control valve position.

Connections with amplitudes that exceed the field screening criteria were reassessed at the predominant frequency and found to be within limits. A number of connections were detuned or dampened so that vibration levels were reduced.

Spectral data was reviewed to determine if peak energy at the dominant frequencies exceeded accepted industry standards. This data supported continued operations at Phase II flows and increasing flows to Phase III levels for further testing.

High Point Vents

On June 8th, continuous monitoring points at Severence PS were moved to high point vents to determine the response. The high point vents consist of a 1" nipple welded into the main pipe via a socket welded connection with a weld by threaded ball valve connected to a nipple with a second valve FNPT x FNPT ball valve that was capped with a pipe plug.

High levels of vibration were found when the control valve was pinched >50%. Consistent overall values were found to be up to 5 ips with intermittent spikes up to 16 in/s when PCV's pinched as part of line pressure control.

On report of the high level of vibration, further assessment was completed. The high levels of vibration were assessed in the frequency domain at points corresponding to high levels of overall vibration. The predominant frequency was found to be at approximately 77 Hz which corresponded to the natural frequency of the attachment.

The vibration amplitude was assessed against EDI/SWRI screen criteria and found to be at a level that required remedial action. To increase the natural frequency of the attachment and remove areas of high levels of stress at threaded connections, all high point vents were removed from all fixed speed sites and as an added precaution, at variable speed sites as well.

Vibration testing after the modification showed vibration with in limits when the PCV was open and vibration spikes during start up and shutdown of the station where the PCV opens and closes. Vibration was assessed in the frequency domain at one of the spikes in overall vibration where it was found that the predominant frequency was approximately 132 hz. The vibration amplitude was assessed against EDI/SWRI screening criteria and found to be with in limits.

Further testing was conducted at stage-2 flow rates where pinch tests were conducted. Overall levels of vibration were found to exceed the field screening criteria of 1.6 ips pk when the PCV was pinched below 40% at Severence PS. Vibration was assessed in the frequency domain. The vibration amplitude was assessed against EDI/SWRI screen criteria where it was found to be within limits.

Further testing was conducted at stage-2 flow rates where pinch tests were conducted.
At Freeman PS, overall levels of vibration were found to exceed the field screening criteria of 1.6 ips pk when the PCV was pinched below 40%. Vibration was assessed in the frequency domain. The vibration amplitude was assessed against EDI/SWRI screen criteria where it was found to be within limits.

<u>Phase III Operations (June 16 to June 22, 2011) (NTD confirm dates)</u>

At Phase III flow rates, data was taken utilizing normal station configurations for the targeted flows, and under conditions with the Pressure Control Valve in a throttled position to simulate a worst case scenario. To simulate worst case conditions a "pinch" test was performed at all fixed speed sites.

<u>Pressure Safety Valve Assembly</u>

Pinch testing at the fixed speed sites resulted in a number of pressure transmitters exceeding the field screening criteria similar to the findings as in Phase-2 operations. Connections with amplitudes that exceed the field screening criteria were reassessed at the predominant frequency and found to be within limits. A number of connections were detuned or dampened so that vibration levels were reduced within limits.

<u>High Point Vents</u>

Further testing was conducted at stage-3 flow rates where pinch tests were conducted. Overall levels of vibration were found to exceed the field screening criteria when the PCV was pinched below 40% at Fort Ransom, Severence, and Freeman PS. Vibration amplitudes that exceed the field screening criteria were assessed at the predominant frequency and found to be within limits.

An FEA analysis of the high point vent assembly was also performed and revealed that allowable stresses were not exceeded. The long term plan is to cut and cap the current assembly as close to the large bore pipe as is possible, and install a newly designed plug valve assembly.

<u>Thermowell Connection</u>

At Ft. Ransom, Thermowell connection was found to exceed field screening criteria. Connections with amplitudes that exceed the field screening criteria were reassessed at the predominant frequency and found to be within limits.

This connection was modeled with FEA in a manner consistent with other components of concern. Stress limits were well within allowable stress limits.

As a result of the above findings and corrective actions it was determined that Phase-III startup requirements were satisfied.

Post Phase III Activities

The daily discrete and continuous vibration measurement program was discontinued. Further testing was completed on the VFD sites with no significant findings.

Findings to Date

Generally speaking, excitation of station piping through resonant frequency response and/or addition of broadband energy occurs when the pressure Control Valve position is <45% open. Some piping components are particularly sensitive to the above described conditions and subsequently exhibit overall vibration levels in excess of the screening criteria requiring additional measures. Details are provided below.

Large Bore Pipe - Vibration levels of the large bore pipe did not appear to significantly vary with increased flow rates when the PCV was greater than 50% open. At positions less than 50% open, the large bore pipe vibration increased in response to greater flow rates yet remained within acceptable limits. Field observance of pipe support contact and spacing revealed that improvements in large bore pipe natural frequency response could be achieved with the re-establishment of design parameters in the support saddle-to-pipe spacing. Further improvements may be possible by the reduction of support spacing in key areas. Further investigation is being conducted.

Small Bore Pipe - Vibration velocities were generally well within acceptable limits under low flow and/or minimal throttling conditions. High PCV throttling conditions resulted in broadband excitation from the last running pump to the pump station discharge piping downstream of the PCV to grade. This broadband excitation results in increased vibration velocities of the small bore piping within the piping section described above. The small bore piping associated with the pumps is predominantly influenced by the operating speed of the pump.

Repairs and Modifications

Prior to restart, all schedule 80 swage nipples used on the thermal relief valves were replaced with schedule 160 fittings. The schedule 160 fitting is a thicker walled material which helps to minimize the effect of operational vibrations and reduces the susceptibility to over torquing during installation. Instructions were provided to installation crews on how to complete the installation of new nipples to avoid over torque installations.

Also prior to restart, bracing was installed on the thermal relief valve piping assemblies at every VFD and fixed speed station. The bracing minimizes the levels of operational vibration and stress on the susceptible fitting and other joints on the piping assembly. Several modifications were made during the Vibration Testing that occurred during the phased restart. These include the addition/tuning of bracing and pipe supports on the Thermal Relief vent valve and the relocation of pressure transmitters.

Additional mitigative measures taken include the completion of NDE Inspections of PT fittings, PSV fittings, Temperature Transmitter connections, Drains, and pig traps. All facilities were also inspected to ensure that settling was not impacting the integrity of the facilities.

In order to minimize the vibrations associated with utilization of the PCV the fixed pump stations were evaluated to determine if modifications to the pump trim would provide a better operating envelope and decrease the amount of vibration while maintaining the flow characterization required to meet system design commitments. It was determined that the Freeman A1 pump, the Ft Ransom A1 and A4 pumps, and the Seneca A1 pump could have the impeller trim modified to optimize the operating conditions. The Freeman A1 and Ft Ransom A4 modifications have been completed. The impellers for Ft Ransom A1 and Seneca A1 have been removed. Both are expected to be modified and installed prior to the end of the month.

Next Steps and Timelines

A system wide outage will take place from August 2, 2011 to August 8, 2011. There are multiple projects that will be ongoing during the outage to ensure the continual improvement of facility operational reliability. Many of these are not associated with the vibration and leaks that were experienced. The vibration related projects are being implemented during this outage to mitigate the potential effects of high vibration on pump station components at fixed speed sites on a priority basis. A conservative plan has been developed to minimize the effects of pressure control valve throttling on the following components:

- Pressure Transmitters (PT103, PT201, PT202, PT203) – The scope includes cutting and capping the old connection and installation of a new ½ inch connection and isolation valve and remotely mounting the three way manifold.

- High Point Vents (each pump suction and discharge expansion loop) – The scope includes cutting and capping the old connection and installing a new 1 inch connection with vented plug.
- Pressure Safety Valve Piping – The scope of work includes a new piping design and brace. The original connection will be cut and capped.
- Thermowells – The scope of work includes off-mounting of current temperature transmitters, cutting and capping of spare thermowell connections, and installation of a new low profile thermowell and RTD for testing and validation purposes.

The above described work scope is focused on mitigating component vibration issues between the station isolation valves and the unit isolation valves. TC Oil Pipeline Operations, Inc. feels the majority of risk regarding failure of components due to high vibration on the Keystone pipeline will be mitigated in the above mentioned work.

Index of Attachments

Attachments omitted due to confidential, privileged, proprietary and/or security sensitive information contained within the documents.