Using Flow Element Transients to Simulate Complex Pipeline Interactions

Background of Client Problems

This facility is a crude oil booster pump station with four reciprocating pumps that sends regular batches of product from tanks to a transportation pipeline (see Figure 1). Onsite dynamic pressure data was captured using DC pressure transducers to investigate a water hammer and valve slamming occurrence after each pump shutdown at the booster station site. The dynamic pressure data was collected simultaneously on either side of the discharge check valves for pumps 1 and 4 and the system was then modeled in detail. This case study illustrates how the water hammer software was used to calibrate the model with field measurements to find a solution to the client's problems.

The operating scenario measured on site was at the end of their product batch when the pumps go offline. The situation used to calibrate the model was pumps 1 and 4 running, with pump 4 shutting down.

Due to confidentiality agreements with our clients, names and locations have not been included with this document.

General Problem Observations

After shutdown of a pump, a loud bang emanating from "the piping system" is heard.

Extreme pressure spikes were measured during this event in excess of 3000psig on the pump side of the check valve; normal operating pressure is around 180psig (see Figure 3). The line side of the check valve experienced pressures up to 330psig (see Figure 2).

Periods of vacuum were measured during the hammer event that lasted up to 0.8 seconds.

Cavitation occurred on both sides of the check valve and in the suction line during the slamming event. This is due to check valve slam combined with the pressure surge.

The model predictions were found to be very sensitive to events occurring at the pipeline meter banks, including the next batch customer coming online.

The positive displacement meters at the pipeline company meter bank allow pressure surges to pass through them.

In Figure 1 the discharge from the pump station goes off towards the pipeline company meter banks.

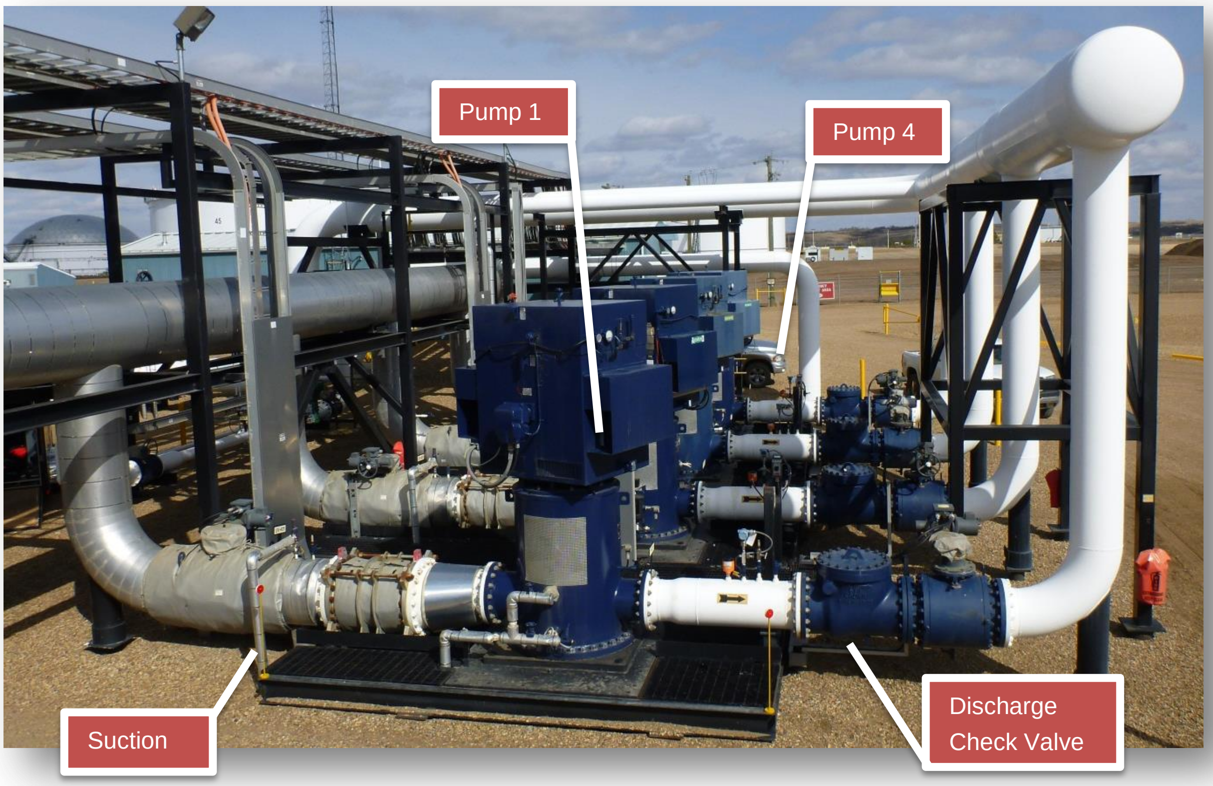

Figure 1 Pump System Photo

Model Tweaking and Validation

There were several unknowns on the downstream piping past the pipeline company meter banks. Because the downstream piping involved pipe from at least two more operating companies, details of this part of the system were not available. As a result, initial model results did not match well with the field data, which led to investigations of the model boundary conditions (see model in Figure 4). Several of the unknowns included:

- The actual second by second pressure and flow profiles through the meter banks
- The sequence of events involving the next company batch coming online once pumps 1 and 4 shutdown
- How these all interacted to produce the response we measured on site

The approach to move forward involved making educated trial and error guesses at what was likely happening at the meter banks during the shutdown sequence. We decided that it would be easier to estimate flow rates rather than pressures, therefore the flow element transients were used at the model boundary to simulate different system scenarios.

We used three flow elements, each contributing a different consideration to the model as follows:

1. The expected flow through our client's booster pump station meter bank (Meter Bank B)
2. The expected flow from the next crude oil shipper coming online
3. The expected flow leaving the next shipper's meter bank (Meter Bank A)

The flow through element 1 (Meter Bank B) was modeled using a flow element transient as a flow reduction flow profile as per pump 4’s speed decrease on site. This transient was activated using a high pressure setting once the pressure wave from Pump 4’s shutdown reached the meter bank.

Flow through element 2 (next oil shipper) was modeled as a flow profile coming online from stop and entering the system. A time based transient trigger was used for this element.

Flow through element 3 (Meter Bank A) was modeled as a flow profile leaving the system and was triggered using a high pressure value setting.

Tweaking of the transient flow profiles and transient trigger settings allowed an iterative approach analysis to occur which eventually led to a very good match of the model predictions with measured field data. Model results (not including valve slam for clarity) are compared with measured field data in Figure 5.

A “Reality Calibrated” Model to Find Solutions

With the field-calibrated model in hand we could then use the conditions measured on site to go ahead and test modifications to the system to improve the system behavior. We explored several options and provided them to the client to remedy the “loud bang” issue they had been experiencing. The client was then able to perform an analysis of the most effective solution to implement from cost, labor, and production schedule standpoints.

Water hammer hydraulic modeling provides the flexibility to vary the induced transient flow profiles with many transient activation options. Without this functionality, modeling a complicated system with many important unknowns would not have been possible.

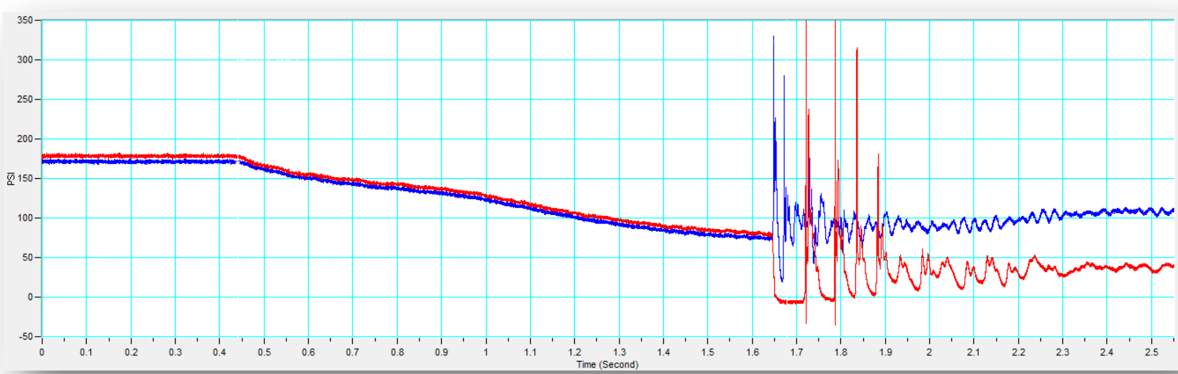

Figure 2 Field pressure data of pump 4 hammer event on inlet side of check valve (RED*), and outlet side of check valve (BLUE).

**The red curve spike amplitudes are in excess of 3000psig and are not shown here for clarity, see below.*

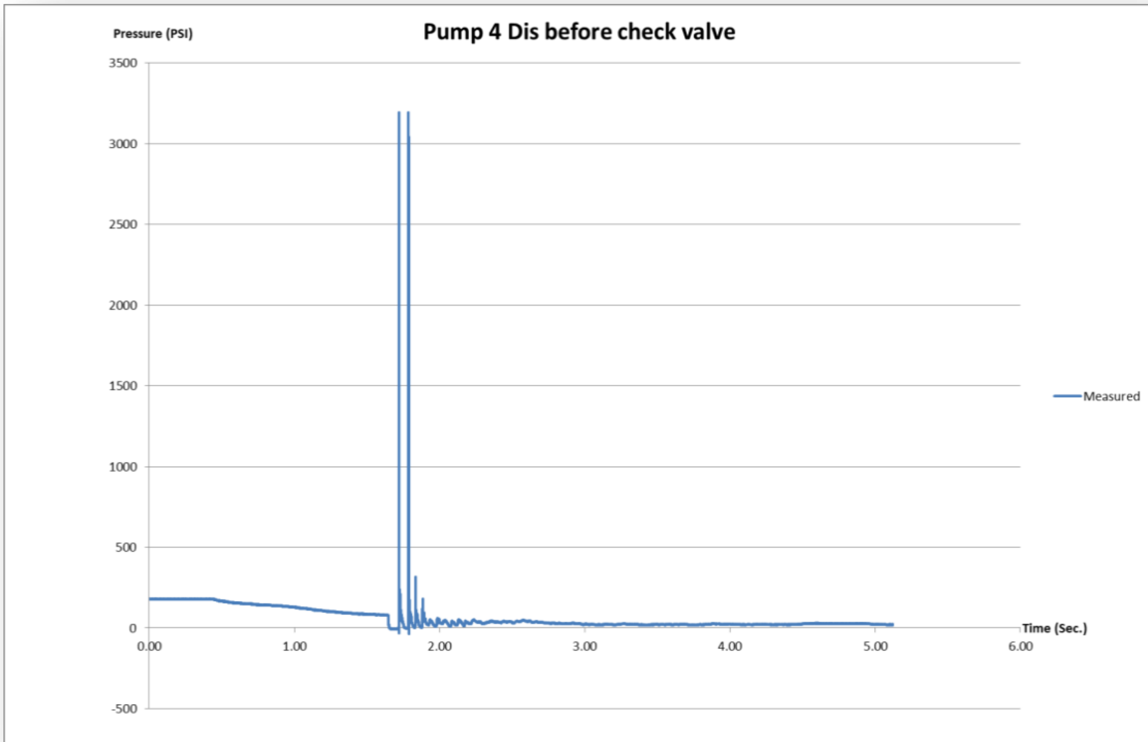

Figure 3 Extreme Pressure Spike on Inlet Side of Check Valve

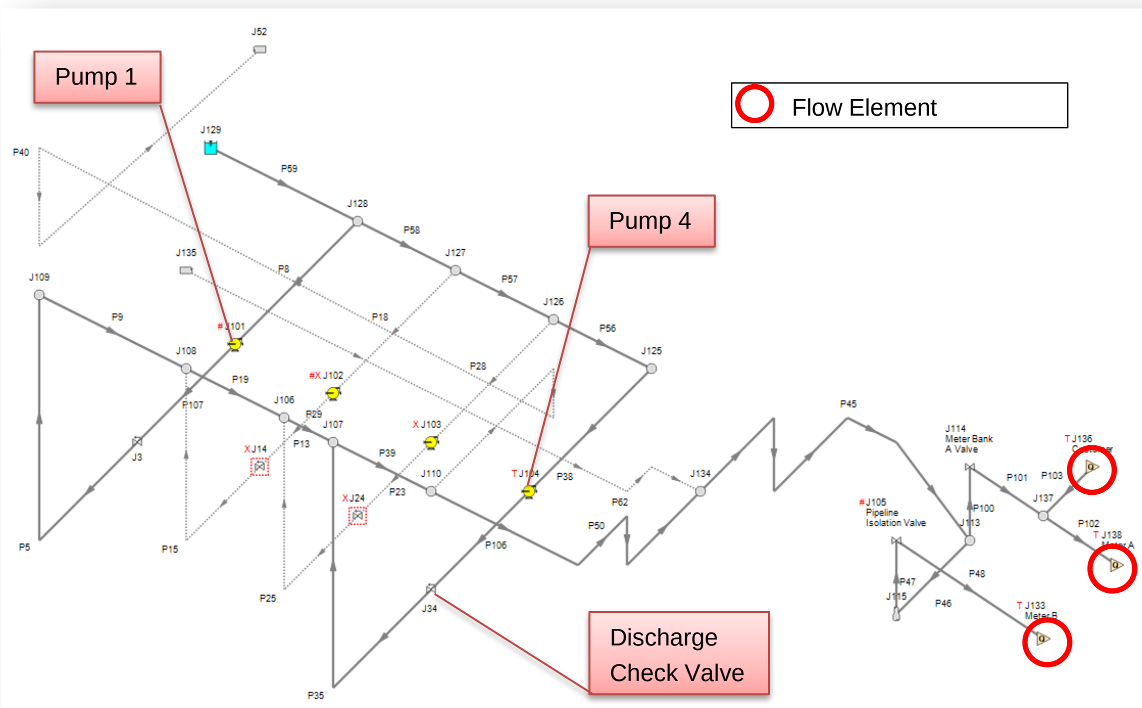

Figure 4 Hydraulic Transient Model

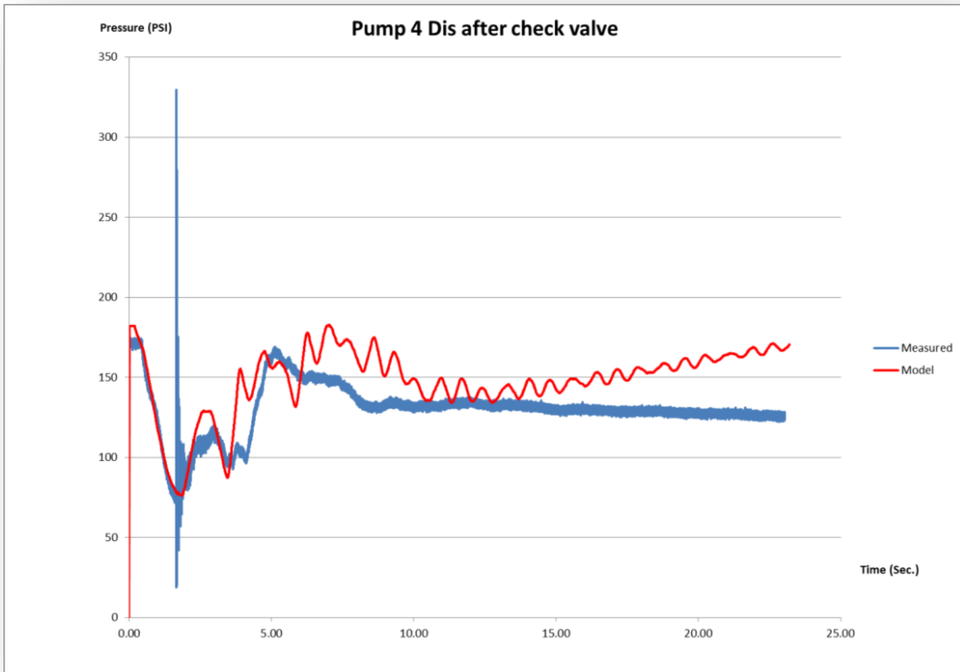

Figure 5 Field Data and Model Prediction Comparison without Valve Slam

For more information about Water Hammer Analysis, contact info@betamachinery.com, or visit our website www.BetaMachinery.com.