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Reciprocating Pump System Dynamic Analysis

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Reciprocating Pump System Dynamic Analysis

White Rock Engineering Services offers a reciprocating positive displacement pump diagnostic service with direct readout of pump performance and piping system response to determine the root cause of any Reciprocating Pump System Problem. Expensive and inappropriate solutions may result if not diagnosed properly. Analysis of the pump and system performance is based on 30 years of reciprocating pump, computer data acquisition, and pumping system analysis experience. Root causes of the potential system problems are discussed on the following pages. Observed operations and recommendations for improvement are discussed on site and presented in a comprehensive report. The initial field survey can usually be completed in one working day with good planning ahead of time. One additional day is required if Wave Blockers (orifice plates) are to be evaluated. Final analysis and report submitted within one to two weeks.

The portable Pump Inspector™ equipment consisting of a personal computer with data-acquisition hardware and appropriate pressure transducers provides live readings of system pressures. These readings are recorded for later analysis and presentation.

The use of a high speed personal computer based data-acquisition system removes all doubt from the recording of random or short-duration pressure pulses such as cavitation spikes. The subtle pulses are important in the interpretation of pump and system performance. Obtaining simultaneous hydraulic pressure data on up to 10 locations is extremely important. Relating the dynamic characteristics at one point in the system to event-related characteristics in another is determined. Comparing different pressure traces allows the correlation of hydraulic pressure disturbances in the system to a definite pump phenomenon such as flow variation, valve openings and closures (acceleration induced pressure spikes), cavitation and system hydraulic resonance.

Although not normally necessary, systems can be monitored over an extended time. Gradual system or pump changes can be detected by utilizing the trigger mode on the data acquisition system. This is particularly important in multiple pump installations where pumps can get in phase or in cyclic operations such as hydraulic press operations, etc.

In preparation for a system dynamic study, considerable time can be saved by pre-planned installation of pressure taps. A sketch of the pumping system from the client is used to plan the location of the system tap points for pressure transducers. The following sections further describe the Pump Survey process:

Reciprocating Pump Analysis
Reciprocating Pump and Flow Line Analysis Displays
Pressure Transducer Installation Procedure
Pump Test Procedure
Wave Blocker (Orifice Plate) Performance
Contact Information

System Operating Conditions and Dynamics

Proper reciprocating power pump operation is dependant on adequate suction conditions and that significant hydraulic resonance is not occurring in the piping system. All reciprocating power pumps have a potential to excite the piping mechanical and/or hydraulic resonant frequencies. Excess hydraulic pressure variation will occur if the pump excitation frequency matches the piping hydraulic resonant frequency.

Net Positive Suction Head (NPSH) Available

Net Positive Suction Head Available is the fluid pressure at the suction manifold of the pump. Inadequate suction pressure results in incomplete filling of the pump chamber and results in loss of volumetric efficiency of the pump and excessive pressure variation in the suction and discharge flow lines. Inadequate fluid pressure in the pump chamber during the suction stroke can result in excessive crosshead shock loading that leads to power-end and drive component failures. Fluid cavitation and attendant damage can result from low NPSH Available even though there adequate pressure to fill the pump chamber. Piping system hydraulic resonance in the suction can also result in fluid cavitation.

Piping System Hydraulic Resonance

Hydraulic resonant frequency excitation potential increases with the number of pumps in a common piping system and when a variable speed pump is used. Hydraulic resonance can increase the fluid peak-to-peak pressure variation by a factor of 10 or more. Wave Blockers (Orifice Plates) when applied at the correct location can be used effectively to reduce the magnitude of hydraulic resonance. Stiffer pipe or more piping supports can be used to reduce the pipe vibration but it does not change the hydraulic forces that are affecting the pump and the energy that is being transferred to the supporting structure.

Piping Mechanical Resonance

Suspended piping and piping appendages have mechanical natural frequencies. Relatively small peak to peak hydraulic pressure variation occurring at the mechanical natural frequency of the piping can cause excessive pipe vibration and pipe support failure. Additional pipe supports is the proper solution to reduce excessive vibration resulting from piping mechanical natural frequency vibration.

Reciprocating Pump Analysis

Analysis of Reciprocating Positive Displacement Pump component failure including power -end and prime mover components; and piping vibration is difficult to resolve without knowing the exact cause. Root causes include system conditions, pump operation, pump maintenance, equipment setup, pulsation control equipment size, and piping system mechanical and hydraulic resonance response. A real-time analysis of the pump performance and system response is needed to determine the root cause of the problem to recommend the proper corrective action.

Pump Operation

The reciprocating positive displacement pump is by nature a hydraulic pulse generator. Magnitude of the hydraulic forces generated by the pump can be increased by various components not functioning properly. These include pump valve operation, fluid compression, and piston or plunger packing condition.

Valve Performance

Delayed Valve Sealing resulting in loss of volumetric efficiency, increased dampener size requirement, and increased fluid acceleration induced pressure in suction and discharge flow stream. Factors affecting valve performance are:

Fluid Properties
Valve Springs
Valve Design
Worn Valves
Fluid-End Design
Net Positive Suction Head Available (NPSHA)

Delayed Valve response causes much higher pump chamber pressures than normal. The high chamber pressure may cause an overload of all pump mechanical components including drive shafts and the motor or engine as well as increased fluid acceleration induced pressure spikes in the suction and discharge flow stream. Other factors include:

Valve Stiction
Unbalanced Valve Loading

Fluid Compression Delay

All fluids are compressible and result in some delay in pump suction and discharge valves opening. Increased delay results in higher hydraulic flow and acceleration induced pressure disturbances. Organic fluids generally result in longer compression delays because they are 2 to 4 times more compressible than water. The extent of delay is a function of the following:

Fluid Properties
Entrained Gas
Fluid Cavitation
Pump Fluid-End Design

Piston or Plunger Packing Leaking

Pump pressurizing seal failure results in increased delay of pump discharge valve opening with increased hydraulic flow and acceleration induced hydraulic forces in the discharge flow lines.

Pulsation Control Equipment

Pulsation control equipment is important in reducing the hydraulic pressure forces applied to all the mechanical components in a pumping system. Pulsation control equipment is designed to stabilize the velocity variation of the reciprocating positive displacement pump. Proper sizing and setup is important to performance of the pulsation control equipment.

Sizing

Pulsation control equipment sizing is based on the near ideal operation of the pump. Larger than normally recommended pulsation control equipment may be required as pump and system conditions move away for the ideal. Pumping systems have been observed that require up to 4 times larger pulsation control equipment to obtain the desired level residual peak-to-peak hydraulic pressure variation.

Setup

Location of the pulsation control equipment is critical to its performance. Recommended location for the pulsation control equipment is within 6 times the nominal pipe diameter of the pump suction and discharge connections.

Generally pneumatic (Nitrogen filled) pulsation control equipment requires a Nitrogen charge be installed for proper operation. Recommended Nitrogen charge pressure varies significantly by manufacturers. Each manufacturer has a recommended Nitrogen charge pressure for a given operating pressure range. Systems with a wide operating pressure range may cause the pulsation control equipment to operate outside a recommended pressure range for a given Nitrogen charge pressure.

Pump Inspector™ - Reciprocating Pump and Flow Line Analysis

The Pump Inspector™ Diagnostic System provides reciprocating power pump analysis with direct readout of pump and piping system performance.

Portable field equipment consisting of a personal computer with data-acquisition hardware and appropriate pressure transducers provides live readings of system pressures. These readings are recorded for later analysis and presentation.

A reporting module is used to view and analyze the pump and piping system test results. The Pump Module displays the overall performance of the pump for each revolution of the pump. Individual pump chamber pressure versus the pump crank position in degrees of rotation along with chamber operating parameters is displayed. Fluid pressure in the suction and discharge flow lines is displayed in the time and frequency domain. Calculated pump data is output to an Excel file with the capability of displaying pump and system results based on time, frequency, operating pressure or pump speed. Representative results are shown on the following pages. The

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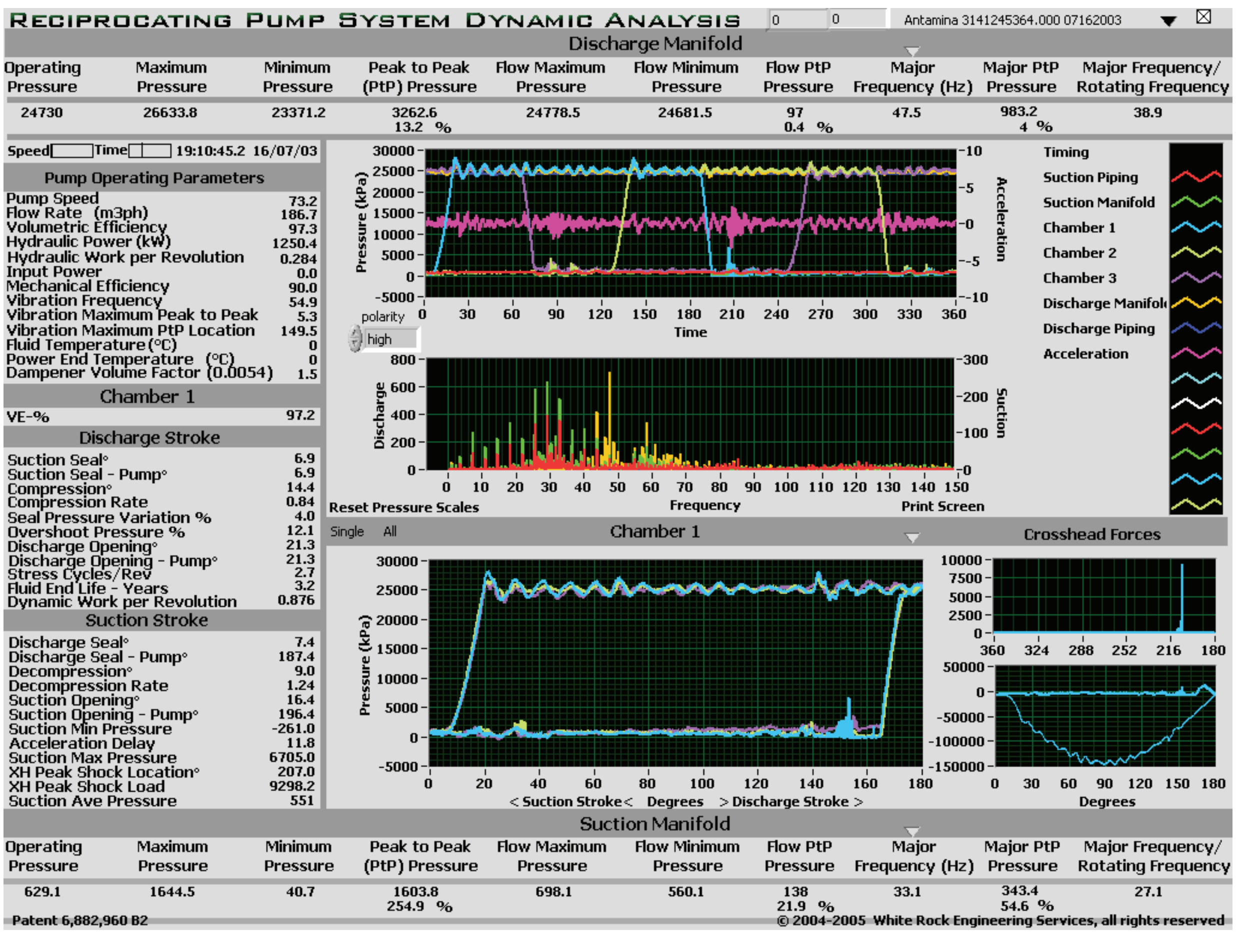


Pump Test Procedure

Piping systems in pumping applications are becoming more complex as more pumps are used to perform pumping operations. The combination of variable pump speed and a complex piping system results in a high potential for hydraulic resonance (high peak to peak pressure standing waves). A Triplex pump generates a primary hydraulic excitation force at 3 times per revolution of the pump as well as a secondary hydraulic force at 6 times per revolution of the pump. For a Quintuplex pump the excitation forces occur at 5 and 10 times per revolution of the pump. As an example, a triplex pump operation in a range of 60 to 120 strokes per minute will generate an excitation force in the frequency range of 3 to 12 Hz depending on actual pump speed.

Pump room piping hydraulic resonance and mechanical natural frequencies excited by the reciprocating pumps are determined by the following procedure for both fixed and variable speed pumps.

1. Instrument the pump that is furthest from the discharge flow line.
2. Mount vibration sensor at location of most noticeable piping vibration.
3. Setup piping system for desired flow path.
4. Open all block valves to other pumps as though they were going to be operating.
5. Start the instrumented pump and run at maximum speed for 15 minutes to allow the fluid system to stabilize.
6. Start Data Acquisition System and collect one minute of pumping system data.
7. (Options)
    a) Continue to collect data while decreasing pump speed 5 strokes per minute every 30 seconds until Minimum Operating Speed is reached.
    b) Continue to collect data while changing suction or discharge pressure.
8. Review Pump and Flow Fine data for pump problems and hydraulic and mechanical resonance.
9. If a hydraulic resonant condition is observed, then install Wave Blockers (orifice plates) at locations to be determined.
10. Repeat steps 5 through 8.

The following page contains a before and after chart of peak-to-peak pressure variation of an actual installation where Wave Blockers (Ceramic Orifice Plates) were installed to eliminate the hydraulic response to the system piping. The three dimensional chart displays peak-to-peak pressures occurring at each frequency for a given pump speed. The normal excitation frequency for a triplex pump is 3 and 6 times the pumps speed. As pump speed increases the excitation frequencies increase. Without the Wave Blockers, the system experienced a hydraulic resonance at 7 Hz. The system experienced normal levels of peak-to-peak pressure variation after installation of the Wave Blockers. The increase in peak-to-peak pressure variation after the installation of the Wave Blockers is the result of normal decreased gas volume in the pneumatic pulsation dampener as operating pressure increased.

Pressure Transducer Installation Procedure

1. To obtain uniformity of data collection, standard pressure and accelerometer transducer locations are used and identified by the following alphabetic codes listed below:

A .... Suction Piping
B .... Pump Suction Manifold
C .... Pump Chamber
D ....Pump Discharge Manifold
E ....Discharge Piping
V ....Vibration

2. Pump chamber pressure transducers (C) are installed in the plunger cover plate after drilling and taping for ¼" NPT.

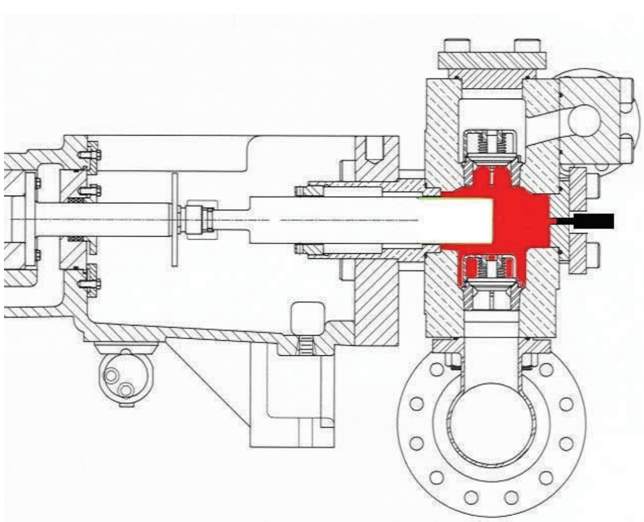
3. All pressure transducers require a 1/4" FPT Pipe connection.

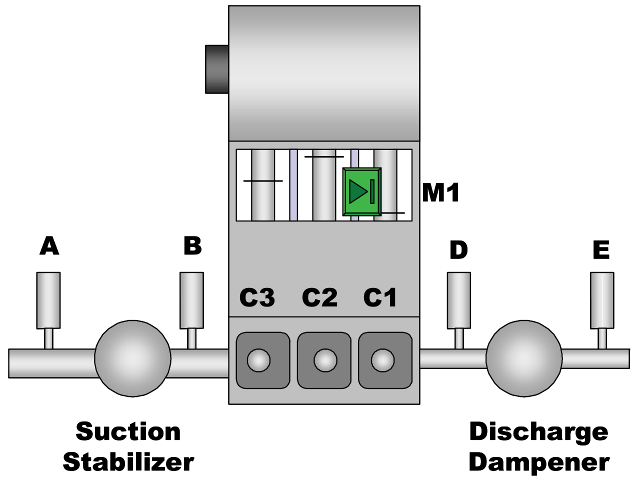
4. The pressure taps should be on the horizontal centerline of the pipe. Gas entrapment can occur if the transducer is mounted on the top of the pipe. Sediment entrapment in a slurry pumping application can occur if the transducer is mounted on the bottom of the pipe. Top and bottom of pipe installations can be used when care is taken to insure that neither of the above conditions is affecting the results.

5. Transducers should be located as close to the pump inlet and outlet as possible.

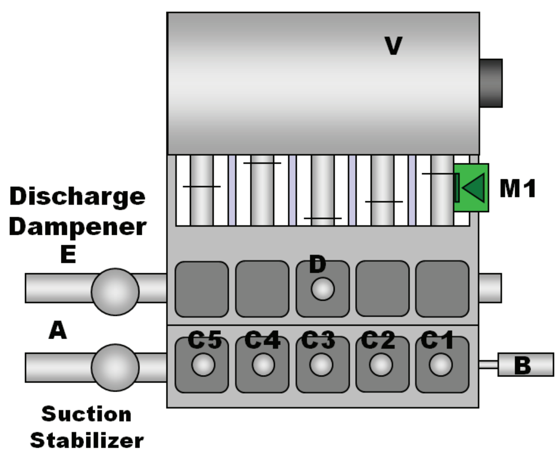
6. The data acquisition system is capable of obtaining up to a total of 10 pressure measurements, so the recommendation is to instrument all pump chambers up to a total of 6 along with the standard two suction and two discharge test points. Valve and pump dynamics are determined by use of a mechanical-maker and a pump chamber pressure trace. Valve opening delays caused by the combination valve sealing delay and fluid compression delay are determined. It is necessary to obtain at least one cylinder pressure measurement (transducer C) as a marker to determine if the system hydraulic pressure disturbances are related to flow, acceleration, or hydraulic resonance.

7. Transducers should not be left in the cylinder tap under operating conditions any longer than necessary because of high cyclic stress placed on the transducer by the square wave pressure action occurring in a pump's chamber

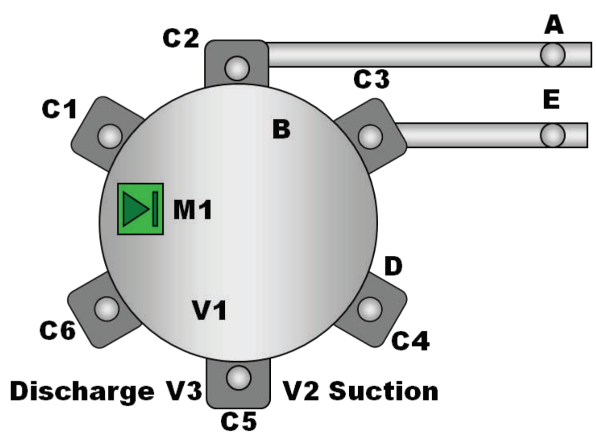




Quintuplex

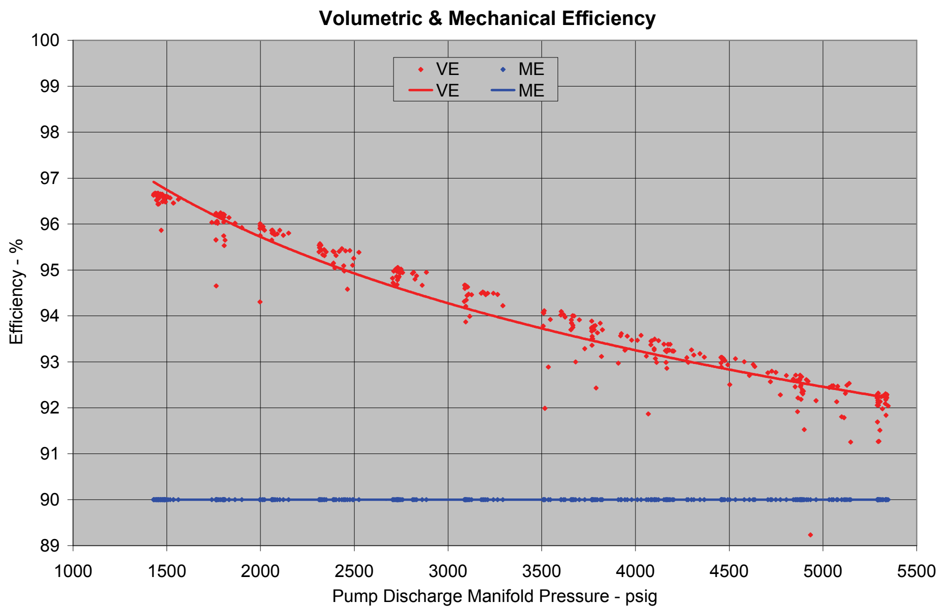


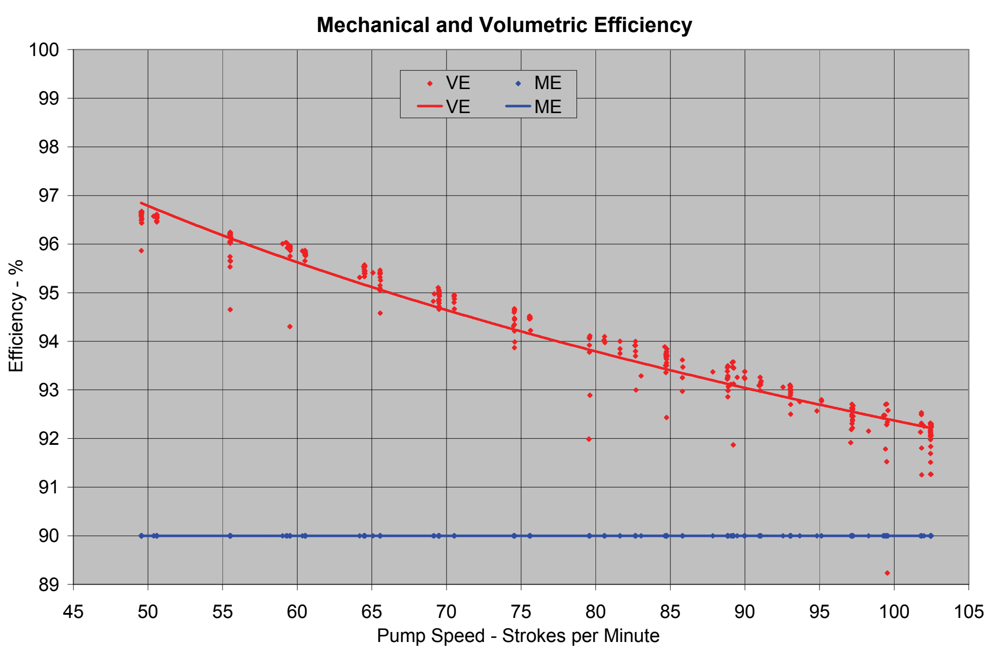
NOV
Hex Pump



Pump Calculated Results

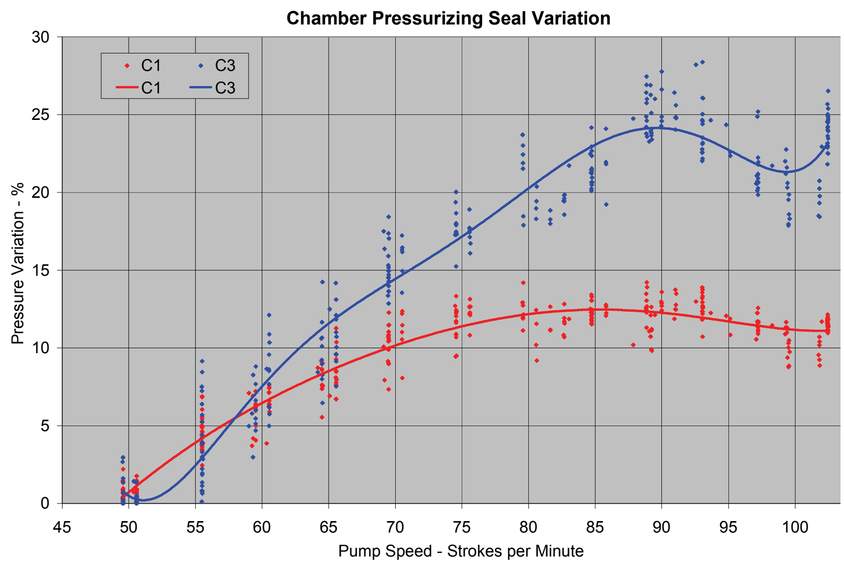
The following charts display the combined effect of pump speed and operating pressure on the volumetric efficiency of the pump. A pump speed test was conducted by taking the pump to maximum pump speed and operating pressure then reducing the pump speed 5 strokes per minute every thirty seconds allowing pressure to fall as pump speed was reduced. A Standard Mechanical Efficiency value is used when no power input data is available.

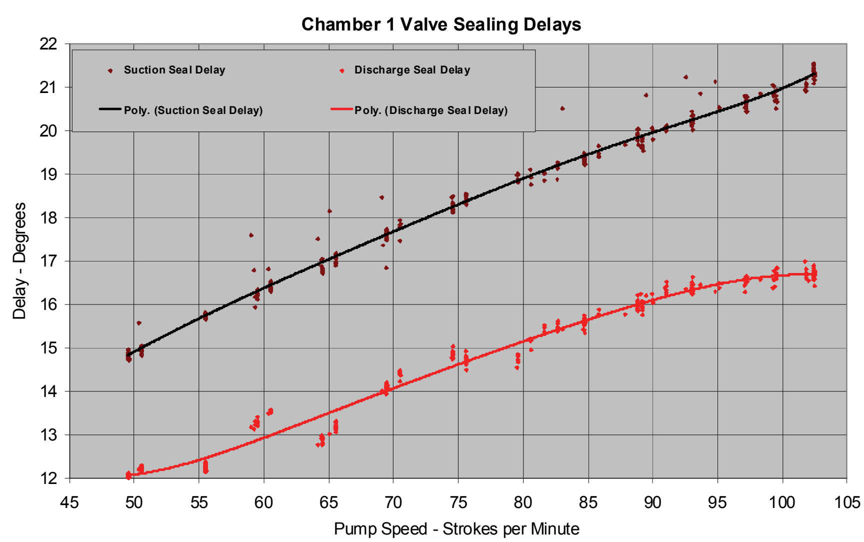




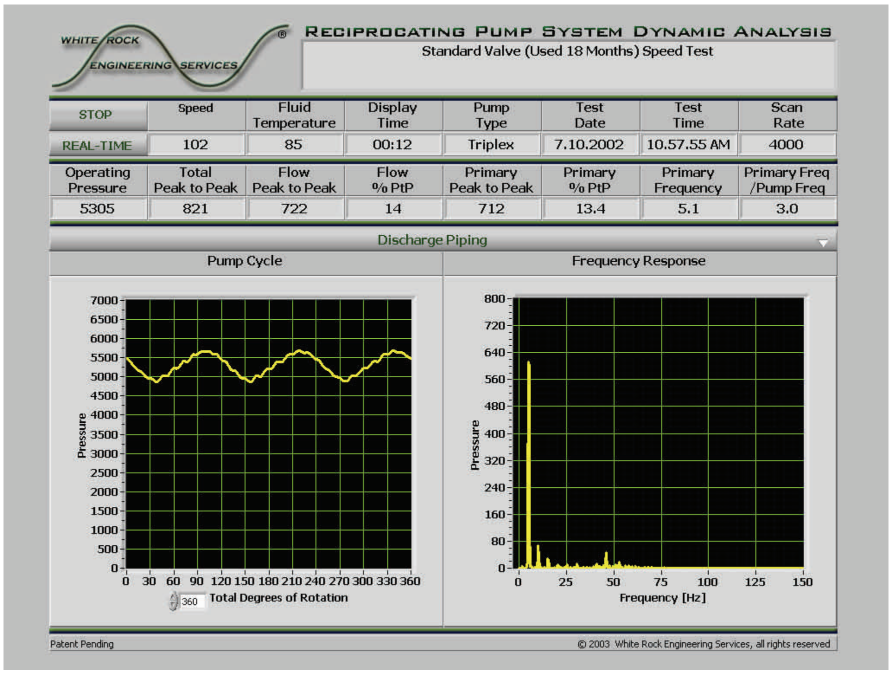
The **Pump Monitor System** calculates the volumetric efficiency of the individual pump chamber, valve sealing delays, fluid chamber compression delays, chamber overshot pressure, and pressure variation during the discharge stroke compression. High variation of pressure during the compression cycle indicates the piston or plunger packing seals are in marginal condition.

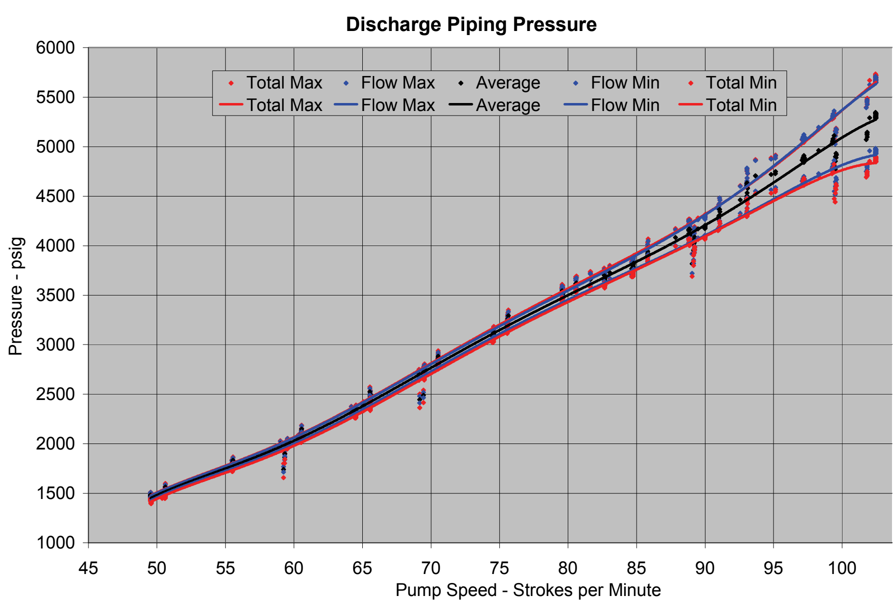
Valve performance is very important to pumping system operation and is determined by the instantaneous results and how the results change between pump cycles. The Valve Timing Chart displays the degrees rotation past the mechanical end of stroke where the suction and discharge valves seal as a function of the pump speed. The chart indicts the valve sealing delay is varying within a range of two degrees at a given speed and is increasing by six degrees as the pump speed increases from 50 to 102 SPM. Valve timing is usually more consistent and should have a sealing delay of less than 10 degrees instead of the 12 to 21 degrees delay observed.



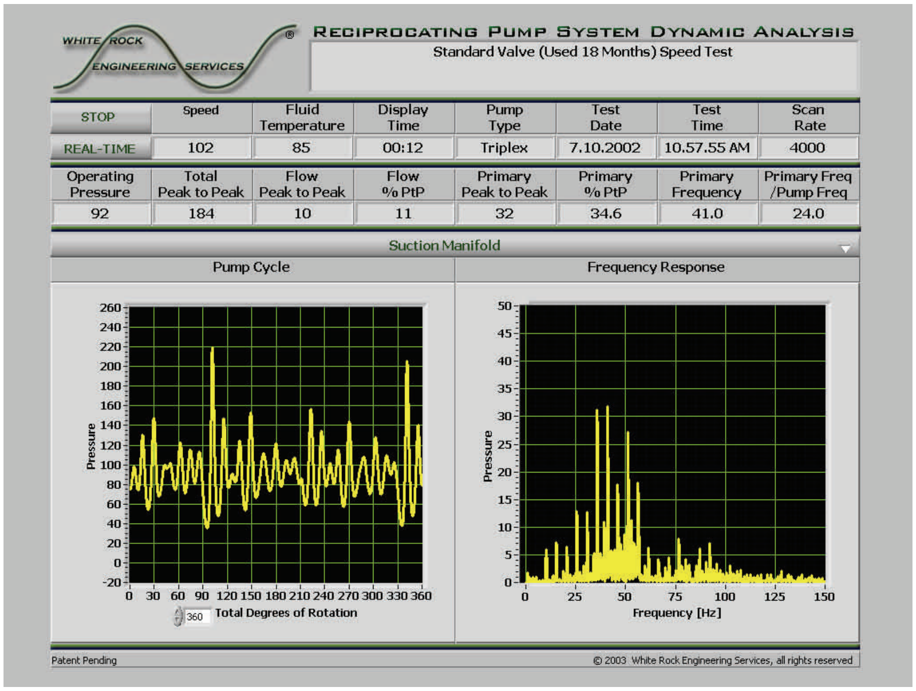


Flow Line Module displays the hydraulic response of the system. The Discharge Flow Line Display shows a piping system resonant condition. The amplitude of pressure variation in the frequency response chart is represented as peak-to-peak pressure variation. Hydraulic resonance is occurring in the discharge piping at 102 strokes per minute.

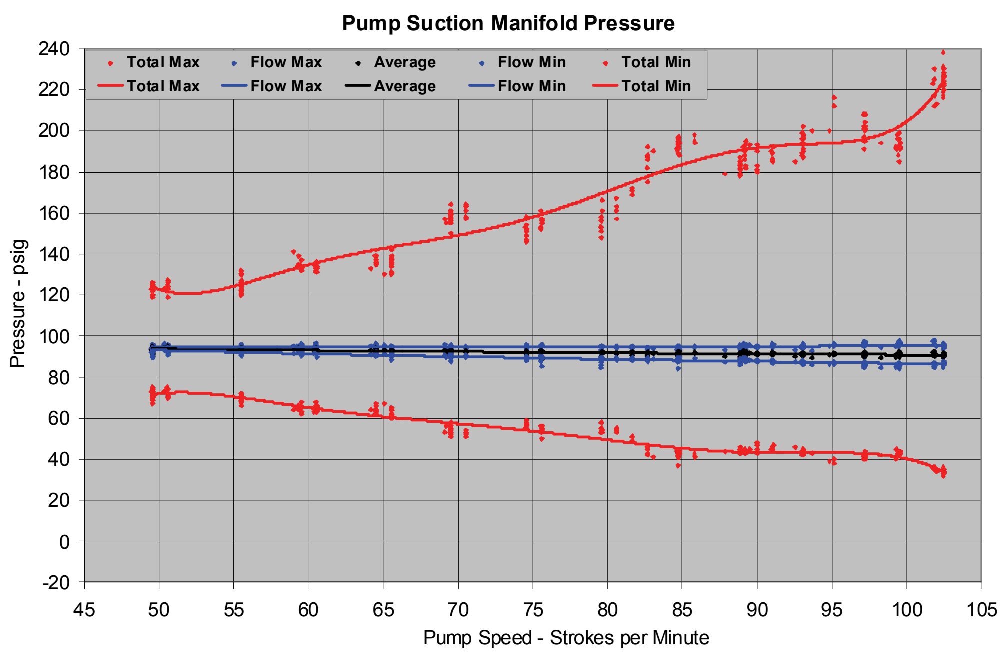




High acceleration head loss response peak pressure is occurring in the pump suction manifold at the pumps maximum speed of 102 strokes per minute.

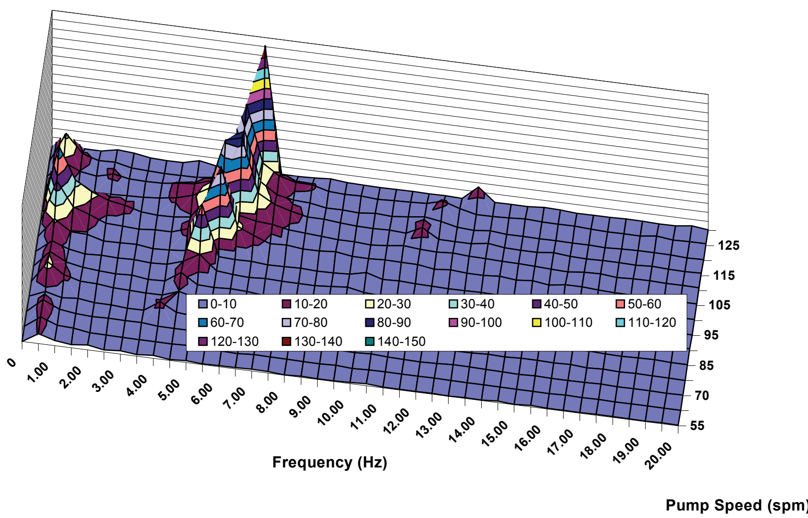


Suction Manifold Fluid Pressure with High Acceleration Pressure Response

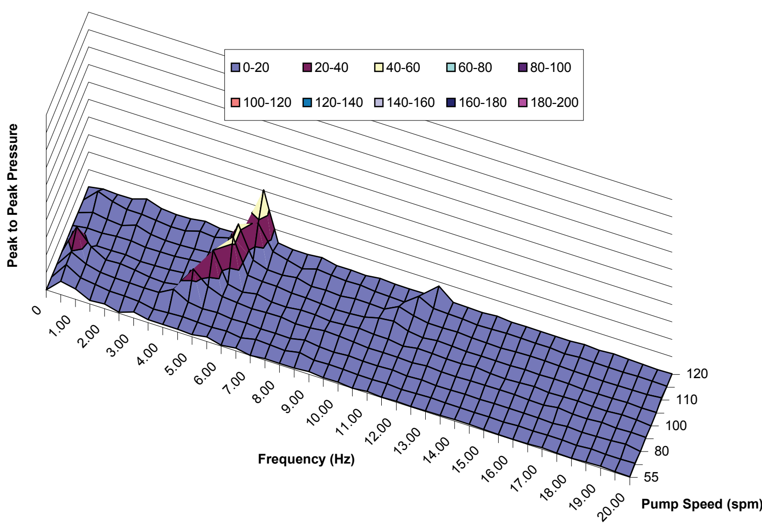


Remediation of excessive piping vibration on North Sea Rig with K20-7500 Discharge Dampener

A 5.5” X 12” SA Triplex Mud Pump equipped with a K20-7500 Pneumatic Mud Pump Dampener experienced hydraulic resonance starting at 80 strokes per minute and increased significantly as pump speed reached 120 strokes per minute. Installation of Wave Blockers in the pump room high pressure discharge piping reduced the peak-to-peak hydraulic pressure variation from 140 psi to 55 psi a reduction of 61% eliminating excessive mechanical vibration.



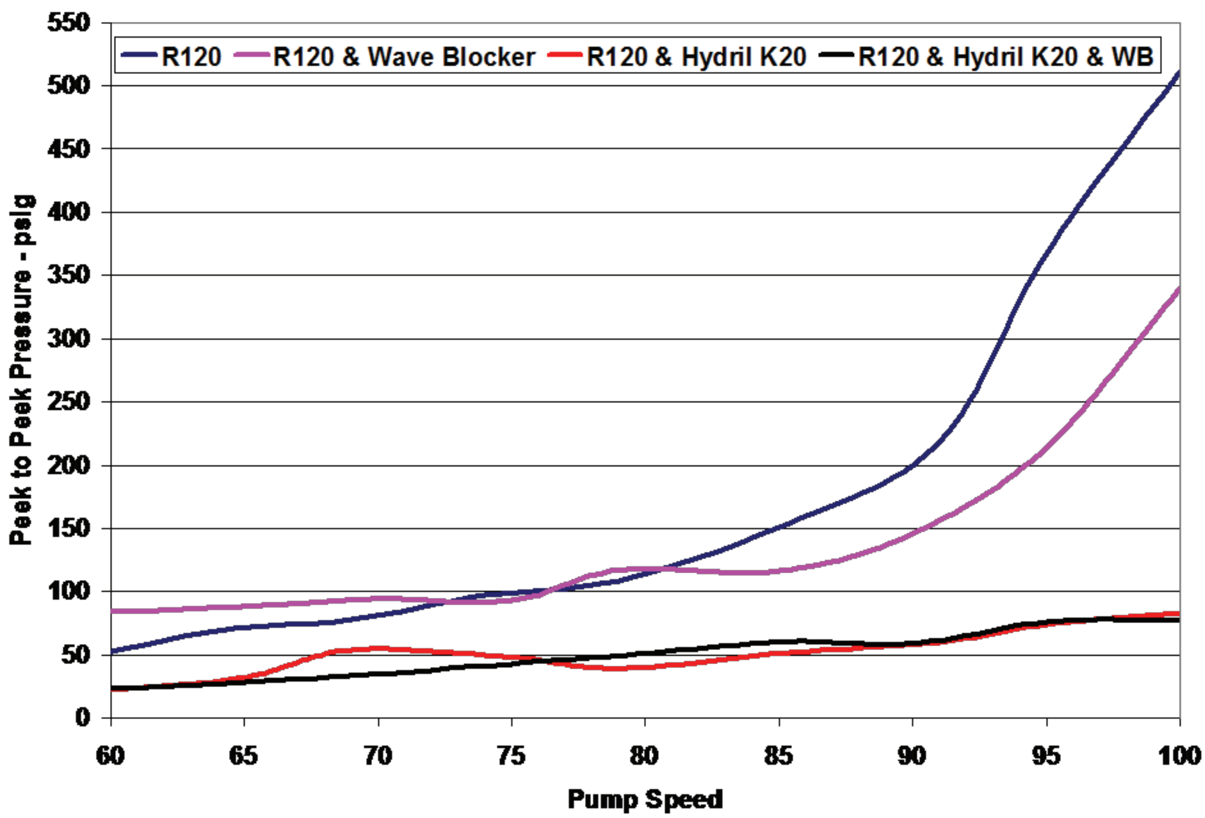
Initial System Results



Results with Wave Blockers Installed

Remediation of excessive piping vibration on GoM Rig with R120-7500 Discharge Dampener

A 5.5" X 14" SA Triplex Mud Pump with a R120-7500 Liquid Mud Pump Discharge Dampener experienced hydraulic resonance starting at 80 strokes per minute and increased significantly as pump speed reached 100 strokes per minute. Installation of a Wave Blockers in the pump room high pressure discharge piping reduced the peak-to-peak hydraulic pressure variation from 510 psi to 335 psi a reduction of 34%. The addition of a K20-7500 Pneumatic Discharge Dampener reduced the peak-to-peak hydraulic pressure variation from 510 psi to 76 psi a reduction of 85%. The Wave Blockers were not necessary with the combination dampeners, however it eliminated a slight resonance condition at 70 strokes per minute and provides the peak to peak hydraulic pressure variation reduction of 34% when operating the system below the K20-7500 Nitrogen charge pressure.



Client List

Pump Manufactures
Abel Pump (Roper Pump)
Aplex-Meyer Pump
APV Gaulin
APV Americas
Continental Emsco (NOV)
Freemyer
Gardner Denver (GD)
Ingersoll Rand (IR)
Kerr Pumps
National Oilwell Varco (NOV)
OPI Pump (GD)
Union Pump
Wheatley-Gaso (NOV)
Wilson Snyder (NOV)
Wirth Pump
Worthington Pumps (IR)

Food Processors
HJ Heinz - Pennsylvania
Kraft Foods – New York
California Milk - California
Dannon Yogurt - Ohio

Pharmaceutical
Eli Lily - Indiana
Bristol-Meyers Squibb - Indiana

Industrial
General Motors – Ohio & Canada
Inca Presswood Pallets - Ohio
US Steel – Indiana
Ford Motor – Canada
Inland Steel – Illinois
Bethlehem Steel - Indiana

Mining Companies (Slurry Pumping)
Kerr McGee Nuclear – New Mexico
Chevron Phosphate - Utah
JR Simplot Phosphate - Idaho
Black Mesa Coal - Arizona
Broken Hill - Australia
Centromin - Peru
Samarco Iron Slurry – Brazil
Valep Phosphate – Brazil
Eastern Associated Coal – West Virginia
JM Huber Kaolin – Georgia
Olympic Dam – Australia
La Perla/Hercules Iron Slurry – Mexico
Minera Antamina - Peru
Comalco - Australia

Drilling Contractors
Ensco - Texas
Global Santa Fe – Malaysia and Singapore
Helmerich and Payne – Texas & GOM
KCA Deutag - Caspian Sea & Africa Offshore
Maersk – North Sea
Nabors – Alaska
Transocean - Singapore, Malaysia, GOM

Oilfield Well Service Companies
BJ Services Company
Schlumberger Technology Corporation

Energy Companies
Petronas Chevron – Malaysia
Aera – California
Unocal – Alaska
Mobil Oil– High Island (GOM)
Kerr McGee – Breton Sound (GOM)
Alberta Energy – Canada
Exxon – Louisiana
Texaco - California
Suriname State Oil Company – Suriname
Pennzoil – Pennsylvania
Occidental – California
Power Services – Wyoming
Standard Oil – Alaska
Oryx Energy – Texas
Conoco - Wyoming

Petrochemical
Cit-Con Oil - Louisiana
Valero – Texas
Unocal – Utah
Arcadian Fertilizer – Louisiana
Castrol - California

Pipeline Engineering Design
Bechtel – Libya
BRASS Engineering International - Chile
Paterson & Cooke Consulting Engineers – S Africa
Pipeline Systems - Mexico

Nuclear Power
New Brunswick Electric – Canada
Palisades Nuclear Power Plant – Michigan

RO Water Purification
Engineered Air Systems - Missouri
Cayman Water Authority - Cayman
American Engineering – Virgin Islands
Paradise Island Water Authority – Bahamas
Ocean Conversion - Cayman
Culligan-Enerserve – St. Martin
Sea Water Systems – Mexico
Aqua Design - Curacao