Screening Pumping Systems
Six Step Action Plan

1. **Screen and prioritize your pumping systems to identify good performance improvement candidates**

2. Get management support for improving the highest priority pumping systems

3. Work with appropriate pumping system specialist and/or in-house team to gather and analyze additional data

4. Identify, economically validate, and implement performance improvement opportunities

5. Document actions and report results to management

6. Repeat *Action Plan* process for other good candidate systems
## Prescreening Form

<table>
<thead>
<tr>
<th>Priority</th>
<th>System name/description</th>
<th>Pump Type [MC, PD, Vacuum, Centrifugal]</th>
<th>Certified Pump Performance Curve</th>
<th>Pump ID/process area</th>
<th>Motor name plate data</th>
<th>Service (e.g., utility, process, etc.)</th>
<th>Time in service (years)</th>
<th>Indicate shared duty pump systems/ in service spares</th>
<th>Voltage</th>
<th>Adjustable speed drive</th>
<th>Throttled (% open if available)</th>
<th>Bypass Re-circ</th>
<th>On/Off</th>
<th>More than one pump/split duty</th>
<th>Not controlled (pumps just run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = High Priority</td>
<td>Grey fields indicate priority data entries</td>
<td>Equipment Information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>B = Med Priority</td>
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<td></td>
</tr>
</tbody>
</table>

### Operating Parameters
(provide if readily available, otherwise indicate with check if it is acquirable)

<table>
<thead>
<tr>
<th>Operating parameters</th>
<th>Design flow rate</th>
<th>Operational flow rate</th>
<th>Design head</th>
<th>Operational head</th>
<th>Static head</th>
<th>Upstream pressure</th>
<th>Downstream pressure (after control valve, or bypass line, etc)</th>
<th>Cavitation at pump or in system?</th>
<th>System maintenance level (Hi/Med/Lo)</th>
<th>Typical flow rates and variation thereof</th>
<th>Duration diagrams</th>
<th>Maintenance Costs</th>
<th>PID / DCS screen-shots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating hours or % of time equipment operates</td>
<td>Power or Current</td>
<td>Flow requirements have changed or are expected to change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### Other symptoms

- Additional Information (is acquirable?)

Source: Pump System Basic Assessment Guide co-developed with BC Hydro
Screening–Primary Data3

- Data on all plant systems that are of interest, those that run 24/7)
  - List of pumps
  - Pump description (including: process area, pumped media, pump type, etc.)
  - Installed motor horsepower
  - Motor rewinds
  - Impeller trims
  - Pipe and valve modifications
  - Yearly operational hours (or percent operation)
  - Control method (control valve, variable speed drive (VSD), by-pass)
  - Maintenance records
Screening–Primary Data

- Operating parameters (power/current, flow, pressure)
- Cavitation at pump or in system
- Load over the full range of operation
- Equipment information (service type, time in service, shared duty, voltage)
- Overall installation
Screening—Primary Data

• Typical flow rates and variations
• Duration diagrams
• Maintenance costs
• Process & Instrument Diagrams (P&ID)/Digital Control System (DCS) screen-shots
Data Analysis - Priorities for detailed investigation include:

• Pump systems with high energy use (large motors that run continuously or frequently)

• Systems with higher than average maintenance costs

• Systems with known problems such as cavitation noise or excess vibration

• Systems that have undergone change of duty
• Systems that are controlled by throttling valves
• Systems that use by-pass or recirculation regulation
• Systems where several pumps are normally run in parallel
• Systems which involve a batch type process/one or more pumps operate continuously
• Systems with frequent on/off cycling of a pump in a continuous process
• Systems with no flow, pressure, or power indication
Prioritize Opportunities

• Rank pumps with opportunities for performance improvement

• Focus on energy use, those with maintenance problems, etc.
End Result from Screening

- List of pump systems and solutions that can be implemented immediately without further analysis
- List of pump systems that need further analysis
  - System’s conditions are steady and a snapshot of performance data is required for the analysis
  - There are changes in system demand over time and the system must be monitored over a longer period of time
Select Pumping Systems for Further Analysis

- Review ability of plant staff to collect additional data and provide solutions
- Consider using an outside pump system specialist
- Contact your electric utility
Typical Failures in Centrifugal Pumps

Source – Mechanical Solutions Inc.
Sources of Damaging Forces in Centrifugal Pumps

- Inlet or Discharge Pressure Pulsations
- "Blade Pass" Pressure Pulsations Due to Blade/Vane Interactions, or Possible Recirculation & Stall
- Torsional Pulsations
- Coupling Imbalance
- Misalignment Due to Pedestal Distortion or Piping Nozzle Loads
- Swirl or Pulsations at Thrust Balance Drum
- Seismic Excitation
- Imbalance or Skew-Mounting of Large Diameter Rotor Components
- Front vs. Rear Shroud Cavity Pulsations
- Suction Pressure Pulsations Due to Inlet Recirculation or Rotating Stall
- Possible Oil Film Instabilities

Source – Mechanical Solutions Inc.
### Common Pump / System Vibrations

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 x – 0.35 x</td>
<td>Diffuser Stall</td>
</tr>
<tr>
<td>0.43 x – 0.49 x</td>
<td>Instability</td>
</tr>
<tr>
<td>0.500 x</td>
<td>Rubbing</td>
</tr>
<tr>
<td>0.65 x – 0.95 x</td>
<td>Impeller Stall</td>
</tr>
<tr>
<td>1 x</td>
<td>Imbalance</td>
</tr>
<tr>
<td>1 x – 2 x</td>
<td>Misalignment</td>
</tr>
<tr>
<td># Vanes x</td>
<td>Vane / Volute Gap</td>
</tr>
<tr>
<td># Blades x</td>
<td>Blade / Diffuser Gap</td>
</tr>
</tbody>
</table>

**Key Factor in Many Problems**

**RESONANCE**

Source – Mechanical Solutions Inc.
What Is Resonance?

A structural or rotor-dynamic natural frequency being excited.

A vibration and operating life problem when there is not enough damping.

Source – Mechanical Solutions Inc.
Six Step Action Plan

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2. Get management support for improving the highest priority pumping systems
3. **Work with appropriate pumping system specialist and/or in-house team to gather and analyze additional data**
4. Identify, economically validate, and implement performance improvement opportunities
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6. Repeat *Action Plan* process for other good candidate systems
Analysis Tools for Pumping Systems
Tools

- Pump system specialists use a variety of tools to analyze pumping systems

Examples:

- US DOE’s PSAT – Gather field measurements and focus on identifying energy savings opportunities
- PSmart – Educational tool to model current system and proposed changes to improve performance
- More tools available in PSM Tool Matrix (both free and commercially available)
- Many pump system specialists have their own proprietary tool or use excel spreadsheets
- Most pump system specialists feel that multiple tools are needed during an assessment
Calculating Shutoff Head

How to estimate the shut off head of a pump (inch sizes)

• At 1750 rpm:

Shut off head = Diameter of the impeller squared

• At 3500 rpm:

Shut off head = Diameter of the impeller squared x 4

• For other speeds you can use the formula:

Shut Off Head = D2 x (new rpm / 1750)
Examples – Valve Equations

Source: PSAT Software
Pump Head

Type of measurement configuration

Suction and discharge line pressures

K_s represents all suction losses from gauge P_s to the pump
K_d represents all discharge losses from the pump to gauge P_d

Suction pipe diameter (ID): 12.000 inches
Suction gauge pressure (P_s): 5.00 psig
Suction gauge elevation (Z_s): 5.00 ft
Suction line loss coefficients, K_s: 0.50

Discharge pipe diameter (ID): 10.000 inches
Discharge gauge pressure (P_d): 124.00 psig
Discharge gauge elevation (Z_d): 5.00 ft
Discharge line loss coefficients, K_d: 1.00

Fluid specific gravity: 1.000
Flow rate: 2000.00 gpm

Differential elevation head: 0.00 ft
Differential pressure head: 274.99 ft
Differential velocity head: 0.54 ft
Estimated suction friction head: 0.25 ft
Estimated discharge friction head: 1.04 ft
Pump head: 276.81 ft

System of units: gpm, ft, hp

Source: PSAT Software
System Curve

System head curve input data

- Fluid specific gravity: 1.00
- System loss exponent, c: 1.30

<table>
<thead>
<tr>
<th>Flow rate</th>
<th>Head</th>
<th>Fluid power, hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>2000</td>
<td>276.8</td>
</tr>
<tr>
<td>Point 2</td>
<td>0</td>
<td>200.0</td>
</tr>
<tr>
<td>Alternate</td>
<td>0</td>
<td>200.0</td>
</tr>
</tbody>
</table>

- Calculated static head: 200.0
- Calculated K' (loss coefficient): 1.1064E-5

System curve source: Condition A + user specified

Curve basis

\[ H = H_s + K'Q^c \]

- H = Total head
- \( H_s \) = Static head
- \( K' \) = Loss coefficient
- Q = Flow rate
- c = dynamic/friction loss exponent

Note 1: \( K' \) here applies to the volumetric flow rate, not the velocity head
Note 2: This simple system method does not apply to complex distribution systems where flow is delivered to multiple elevation or pressure zones.

Source: PSAT Software
Sizing Electric Motors to Pumps

\[
BHP = \frac{Q \times H_T \times Sp.Gr.}{3960 \times Eff.}
\]

where
- \( Q \) = Capacity in gallons per minute (GPM).
- \( H_T \) = Total Differential Head, ft
- \( Sp.Gr. \) = Specific Gravity of the liquid
- \( Eff. \) = Pump efficiency, %

\[
WHP = \frac{Q \times H_T \times Sp.Gr.}{3960}
\]

where
- \( Q \) = Capacity in gallons per minute (GPM).
- \( H_T \) = Total Differential Head, ft
- \( Sp.Gr. \) = Specific Gravity of the liquid

Pump Efficiency \((Eff.)\) = \(\frac{WHP}{BHP}\)

These equations are important as we are going to be calculating bhp in the upcoming exercises.

- Adding a service factor and additional horsepower – it can lead to maintenance problems and higher energy consumption.
- The constant 3960 is obtained by dividing the number or foot-pounds for one horsepower (33,000) by the weight of one gallon of water (8.33 pounds).
- BHP can also be read from the pump curves at any flow rate. Pump curves are based on a specific gravity of 1.0. Other liquids’ specific gravity must be considered.
- The brake horsepower or input to a pump is greater than the hydraulic horsepower or output due to the mechanical and hydraulic losses incurred in the pump. Therefore the pump efficiency is the ratio of these two values.
PSMART: An Analysis

• A small pumping system exhibits the common problem of a pump oversized.

• Several possible system improvements are hydraulically evaluated, and the energy and economic impact on each improvement is discussed.

• Minimum required flow to the heat exchanger is 200 gpm.

• Assumptions:
  • Pump is currently supplying more flow than the required flow the heat exchanger
  • Cost of energy assumed to be $0.10/kW-hr
  • Pump runs 24/7
Defining All the Elements of a Pumping System

- Pump elements
- Process elements
- Control elements
Steps to Generate a System Model

1. **Draw the system** using drag and drop tools

2. **Enter Design Data:**
   - Pipe sizes, Pump curve, Fluid properties, etc.

3. **Enter Operational Data:**
   - Liquid level, Pump speed, Open or closed pipelines, etc.

4. **Calculate** and Explore your system
   - Calculations, Operational Warnings, List View
   - Gradient colors

5. **Investigate** Improvement Options
System Model

FLO-Sheet

Data Input

Help

List Window & Message Window
## System Improvement Options

<table>
<thead>
<tr>
<th>Case</th>
<th>Op Energy Cost (5yr)</th>
<th>Pump Flowrate</th>
<th>Pump Efficiency</th>
<th>Pump Power</th>
<th>Valve dP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original System</td>
<td>$60,097</td>
<td>300 gpm</td>
<td>72.3%</td>
<td>18.4 hp</td>
<td>19.2 psi</td>
</tr>
<tr>
<td>Throttle Valve</td>
<td>$51,605</td>
<td>200 gpm</td>
<td>45.8%</td>
<td>15.8 hp</td>
<td>24 psi</td>
</tr>
<tr>
<td>Trim Impeller (9.8”)</td>
<td>$37,398</td>
<td>200 gpm</td>
<td>49.3%</td>
<td>11.45 hp</td>
<td>10 psi</td>
</tr>
<tr>
<td>Variable Speed Drive (VSD)</td>
<td>$27,762</td>
<td>200 gpm</td>
<td>52.6%</td>
<td>8.5 hp</td>
<td>0 psi</td>
</tr>
<tr>
<td>New Pump</td>
<td>$27,170</td>
<td>200 gpm</td>
<td>69%</td>
<td>7.4 hp</td>
<td>5 psi</td>
</tr>
</tbody>
</table>
System Improvement Options

- Throttled Valve System Curve
- Throttled Valve Operating Point
- Minimum Required Flow Rate
- Original System Curve
- Original Operating Point
- Original Pump Curve
- Pump Curve With New Pump
- Operating Points for Trimmed Impeller, VFD and New Pump
- Pump Curve With Trimmed Impeller and VFD
## System Improvement Options

<table>
<thead>
<tr>
<th>Case</th>
<th>Energy Cost ($ for 5 yrs)</th>
<th>Pump Flowrate (gpm)</th>
<th>Pump Efficiency (%)</th>
<th>Pump Power (hp)</th>
<th>BEP Proximity (%)</th>
<th>Valve Pressure Drop (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original System</td>
<td>63,261</td>
<td>367</td>
<td>64</td>
<td>25</td>
<td>151</td>
<td>21</td>
</tr>
<tr>
<td>Throttle Valves</td>
<td>45,518</td>
<td>255</td>
<td>85</td>
<td>18.3</td>
<td>105</td>
<td>72</td>
</tr>
<tr>
<td>Trim Impeller</td>
<td>22,147</td>
<td>252</td>
<td>70</td>
<td>8.9</td>
<td>144</td>
<td>10</td>
</tr>
<tr>
<td>VSD</td>
<td>21,749</td>
<td>250</td>
<td>70</td>
<td>8.7</td>
<td>144</td>
<td>10</td>
</tr>
<tr>
<td>New Pump</td>
<td>17,507</td>
<td>250</td>
<td>86</td>
<td>7.0</td>
<td>104</td>
<td>10</td>
</tr>
</tbody>
</table>
Use a Systems Approach to Manage your Pumping Systems

• Focusing on individual components overlooks potential cost-savings
• Component failures are often caused by system problems
• Use a total system approach in designing systems and evaluating repair and maintenance options
# System Efficiency

<table>
<thead>
<tr>
<th>Flow required</th>
<th>2500 gpm</th>
<th>2500 gpm</th>
<th>2500 gpm</th>
<th>2500 gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head required</td>
<td>200 feet</td>
<td>150 feet</td>
<td>200 feet</td>
<td>200 feet</td>
</tr>
<tr>
<td>Additional system friction loss</td>
<td>50 ft</td>
<td>0 ft</td>
<td>50 ft</td>
<td>55 ft</td>
</tr>
<tr>
<td>Motor eff</td>
<td>94%</td>
<td>94%</td>
<td>94%</td>
<td>96%</td>
</tr>
<tr>
<td>VFD efficiency factor</td>
<td>100%</td>
<td>98%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Mechanical drive eff</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Pump eff</td>
<td>65%</td>
<td>88%</td>
<td>70%</td>
<td>65%</td>
</tr>
<tr>
<td>Energy cost per kWh</td>
<td>$0.07</td>
<td>$0.07</td>
<td>$0.07</td>
<td>$0.07</td>
</tr>
<tr>
<td>Operating hours per year</td>
<td>3500</td>
<td>3500</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>Factor</td>
<td>Base</td>
<td>Reduce friction by 50 feet.</td>
<td>Increase pump efficiency by 5 points.</td>
<td>Increase motor efficiency by 2 points.</td>
</tr>
<tr>
<td>System efficiency</td>
<td>49%</td>
<td>81%</td>
<td>53%</td>
<td>49%</td>
</tr>
<tr>
<td>System input power required for process</td>
<td>206.6 bhp</td>
<td>116.8 bhp</td>
<td>191.9 bhp</td>
<td>202.3 bhp</td>
</tr>
<tr>
<td>Power required for additional friction</td>
<td>51.7 bhp</td>
<td>0.0 bhp</td>
<td>48.0 bhp</td>
<td>55.6 bhp</td>
</tr>
<tr>
<td>Total power required</td>
<td>258.3 bhp</td>
<td>116.8 bhp</td>
<td>239.9 bhp</td>
<td>258.0 bhp</td>
</tr>
<tr>
<td>Total cost per year</td>
<td>$47,212</td>
<td>$21,350</td>
<td>$43,839</td>
<td>$47,153</td>
</tr>
<tr>
<td>Cost Savings</td>
<td></td>
<td>$25,861</td>
<td>$3,372</td>
<td>$59</td>
</tr>
</tbody>
</table>

## System Data

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

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*Hydraulic*

*Caring Pump Standards Since 1927*
Look Beyond Energy Savings

Energy cost is a top consideration, but there are also values for performing a system assessment:

- Higher Reliability
- Increase Productivity
- Less Equipment Wear and Tear
- Reduced Maintenance Cost
- Reduce Production Losses
- Increase Capacity Utilization
- Reduce Environmental Impact
Improving Performance of Existing Pumping System
Defining the System
Performance Improvement Opportunities - Solutions

- Eliminate unnecessary uses
- Improve Operations & Maintenance (O & M) practices
- Improve piping configuration
- Consider alternative pump configurations
- Change pump speed
Unnecessary Uses

• Using a pump when the fluid is not needed
• Running two pumps when only one is needed
• Continuing to run pumps in a batch-type process when products are not being produced
• Excessive pump head or flow
System Opportunities

• Systems controlled by throttle valves
• High operating hours per year
• Recirculation or bypass line normally open
• Cavitation noise at valves, pumps, or piping
• Systems with multiple parallel pumps always operating
• Constant pump operation in a batch environment or frequent cycle batch operation in a continuous process
System Opportunities Continued

- Systems that have undergone a change
- Variability of operation
- High system maintenance
- Motor tripping out
- Larger pumps
- Excessive seal leakage & packing problems
Excessive Valve Throttling is Expensive

- Lower pump and process reliability
- Higher energy consumption
- Sub-optimal process control
  - increased variability
  - manual operation

Pumps are tightly associated with control loops and should be considered an integral part of the automation architecture
Change Pump Speed

- Slower motor
- Two-speed motor *
- Changes to belt drives/gears *
- Variable Speed Drives
  - Variable Frequency Drive
  - Magnetic Drive
  - Fluid Drive
Variable Speed Pumping

- Why use a variable speed pump?
- When to use variable speed?
- When not to use variable speed?

Source: Section supplied by Manitoba Hydro
Consider System Demands

Start

Confirm system and duration curves. Establish if not available.

Consider reducing system losses

Is duty available?

VFD potentially useful

Mostly friction (rotodynamic only)

VFD potentially useful

Does pump run most of the time?

VFD almost certainly beneficial

Flow Chart to assess the suitability of retrofitting a VSD to an existing pump system

NO

YES

Confirm existing fixed speed pump correctly sized

Consider modification or replacement equipment

Retain existing installation if efficient

Check overall benefits include non energy items ie: reduced maintenance cost

Calculate total annual operating cost with alternative system solutions

Are existing pump and motor suitable for proposed variable speed

Select drive and perform financial justification

NO

YES

NO

YES

NO

YES

Source – Hydraulic Institute LCC Guide Book
Throttle Control

- Valve throttling increases system head resulting in excess power consumption
- Excess energy noted in blue area
- Excess energy impacts equipment reliability
• Bypass lines require more flow, which results in excess power consumption.
• Excess energy impacts equipment reliability
Variable Speed Control

- No excess energy used by the system
- Reliability is maximized
When to use Variable Speed?

Pump and System Curves Perpendicular
When Not to use Variable Speed Pumps?

No Variability? Use Impeller Trim or Reduced Fixed Speed

Pump and System Curves Parallel
System Implications to Consider

VFD Pump Systems

• Select pump duty point to the right of BEP

• Consider full speed motor / VFD efficiency?

• Motor heat load due to drive wave form ?

• Check cable lengths (Critical Cable Length Calculation)

• Check if filters are needed (Inlet at drive or termination)

• Design VFD for by-pass operation at 60Hz
Checklist for VFD Pump Operation

• TDH vs. Static head?
• Length of power cables?
• Minimum speed
  — Where on pump curve?
  — Cooling issues?
• Harmonic filters?
• Shielded signal cables?
• How will control be programmed?
Real World Example
Real World Example

Three Pumps

• 150hp is the main pump.

• With increased demand, the 50hp is started.

• With even more increased demand, 150, 50 shut down, start 250hp.

• Finally, run all three together.

• All adjustments done manually.

• Circulation loop (blue valve) – 6” valve into 2” restriction, back into 6” pipe – controlled with a “dump” valve.

Lots of cavitation
Real World Example

Average demand 800-1000 gpm

150 hp pump delivered 1500 gpm

Pumping more water than required
Choose Combinations of Pumps & Controls to Suit the System

- Pressure needed was not 130psi, but 100psi (230 ft. of head).
- Retrofitted to use 150hp pump all the time with a VSD.
- New average power is 73 kW.
Key Points

• Use a system approach to design and manage the pumping system operation

• Understanding the solutions available to improve performance with help you realize that there may be more than one solution to solve the problem!

• Variable Speed Drives are best applied when demand varies over time
Developing an Action Plan
Six Step Action Plan

1. Screen and prioritize your pumping systems to identify good performance improvement candidates
2. Get management support for improving the highest priority pumping systems
3. Work with appropriate pumping system specialist and/or in-house team to gather and analyze additional data
4. Identify, economically validate, and implement performance improvement opportunities
5. Document actions and report results to management
6. Repeat Action Plan process for other good candidate systems
Conclusion

• If you want to improve your pumping systems, follow the plan:
  • Create a partnership between production, management, purchasing, etc.
  • Find out what they consider important
  • Begin with something small and involve production
  • Always document everything that you do
  • Maintain ongoing communication with production and management
  • Measure and report the impact of system changes in terms that are important to management and production (show them the money)
  • Use life cycle cost analysis
Conclusion

• If you want to improve your pumping systems, follow the plan:
  • 1\textsuperscript{st} step is to understand pump system optimization
  • 2\textsuperscript{nd} step conduct comprehensive assessment
  • 3\textsuperscript{rd} step implement process improvements
  • 4\textsuperscript{th} step track results
  • 5\textsuperscript{th} present results to management
  • 6\textsuperscript{th} continuous improvement

Sustainable Growth
Thank You

Questions / Comments?