FLOW AND FUNCTION: FACETS OF LARGE VERTICAL PUMPS, MOTORS, AND VFDS

Ty Tadano, PE
Senior Engineer

Jen Murphy, PE, CSE
Senior Consultant

PRESENTATION OVERVIEW

Goals

- Understand key design elements
- Small items that make a BIG difference

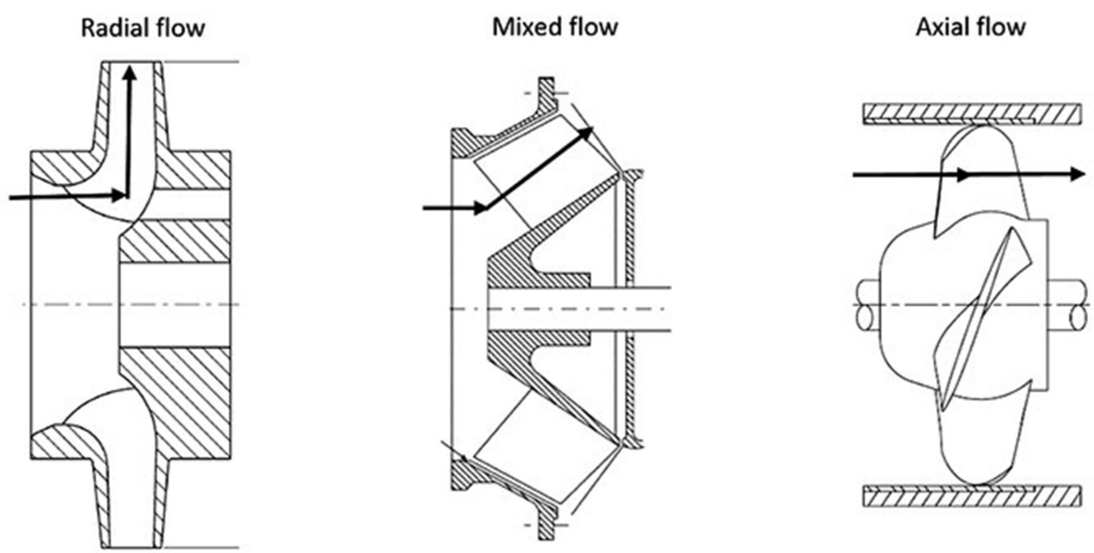
Pump Overview

Specifying and Designing Large Pumps

- Regulatory Compliance
- Acceptance Grades
- Transients
- Vibration / Structural
- Electrical Considerations

Case Studies

WHEN/WHERE ARE "BIG" PUMPS USED



Higher Pressures

distribution, finish water pumps

Higher Flows

intakes, treatment, flood control

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PUMP SPECIFIC SPEED

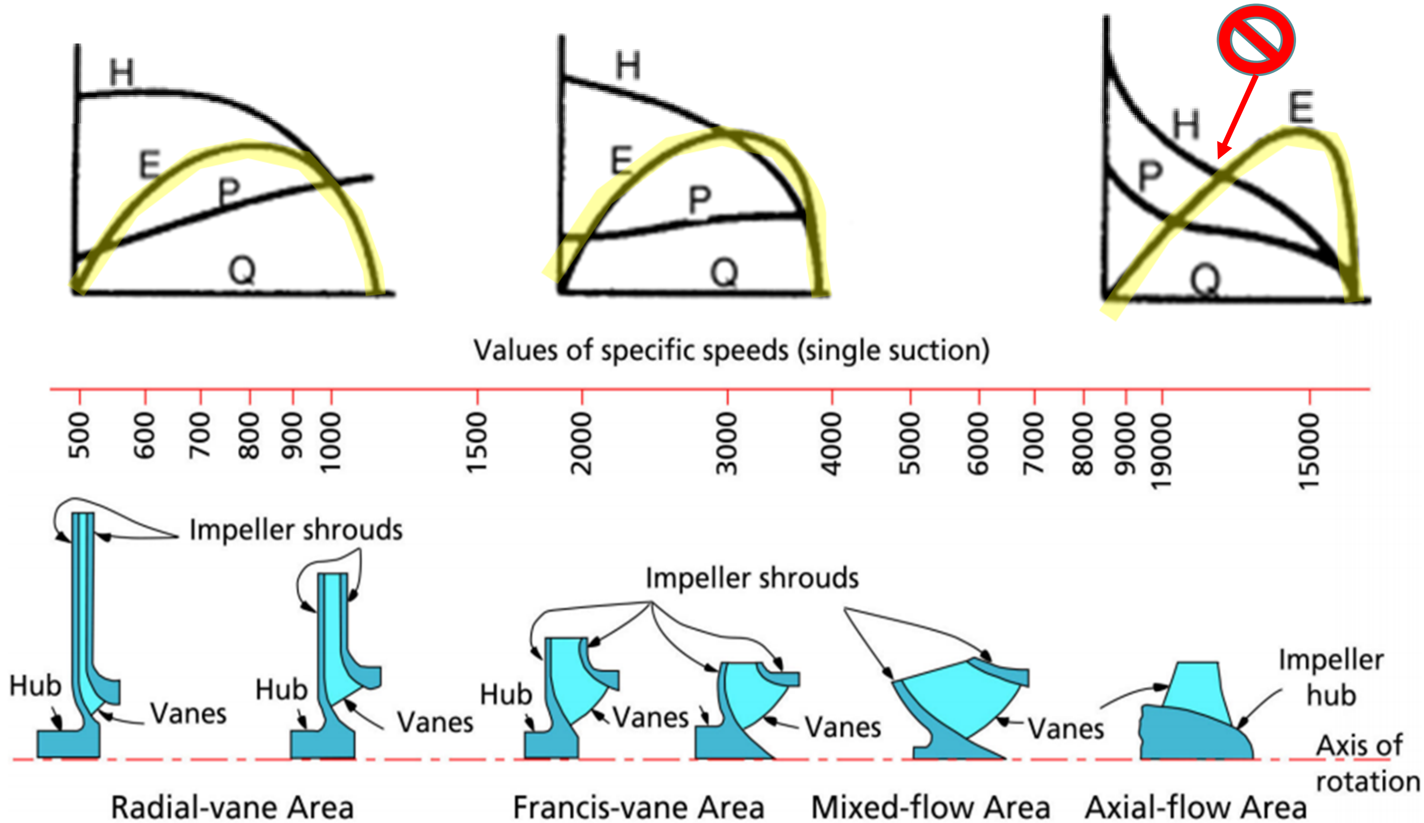
$$N_s = \frac{n\sqrt{Q}}{H^{0.75}}$$

N_s is Specific Speed (dimensionless index)

n is pump rotational speed (rev/min)

Q is flowrate (gpm) at best efficiency point

H is total head (ft) at best efficiency point



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PUMP OVERVIEWS

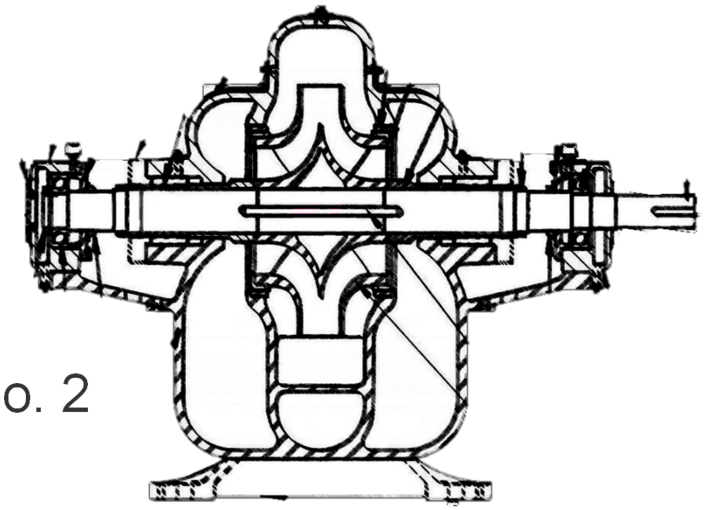
Vertical Turbine Pump

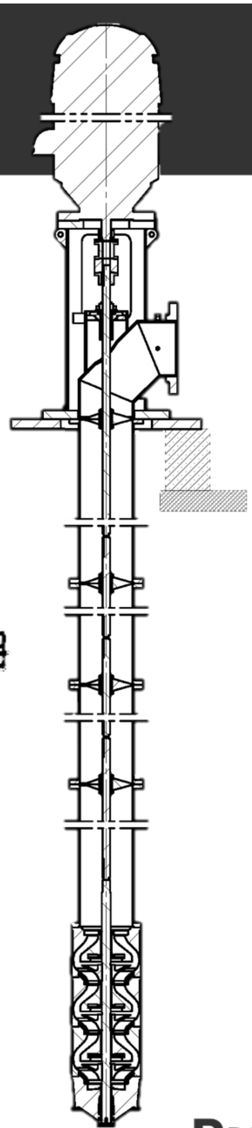
-JWC Finished Water PS No. 2
(400HP, 800HP)

-Baltimore City, Cromwell PS
(500HP, 1250HP)

Split Case Centrifugal

-Baltimore City, Pikesville PS No. 2
(700HP, 1000HP)





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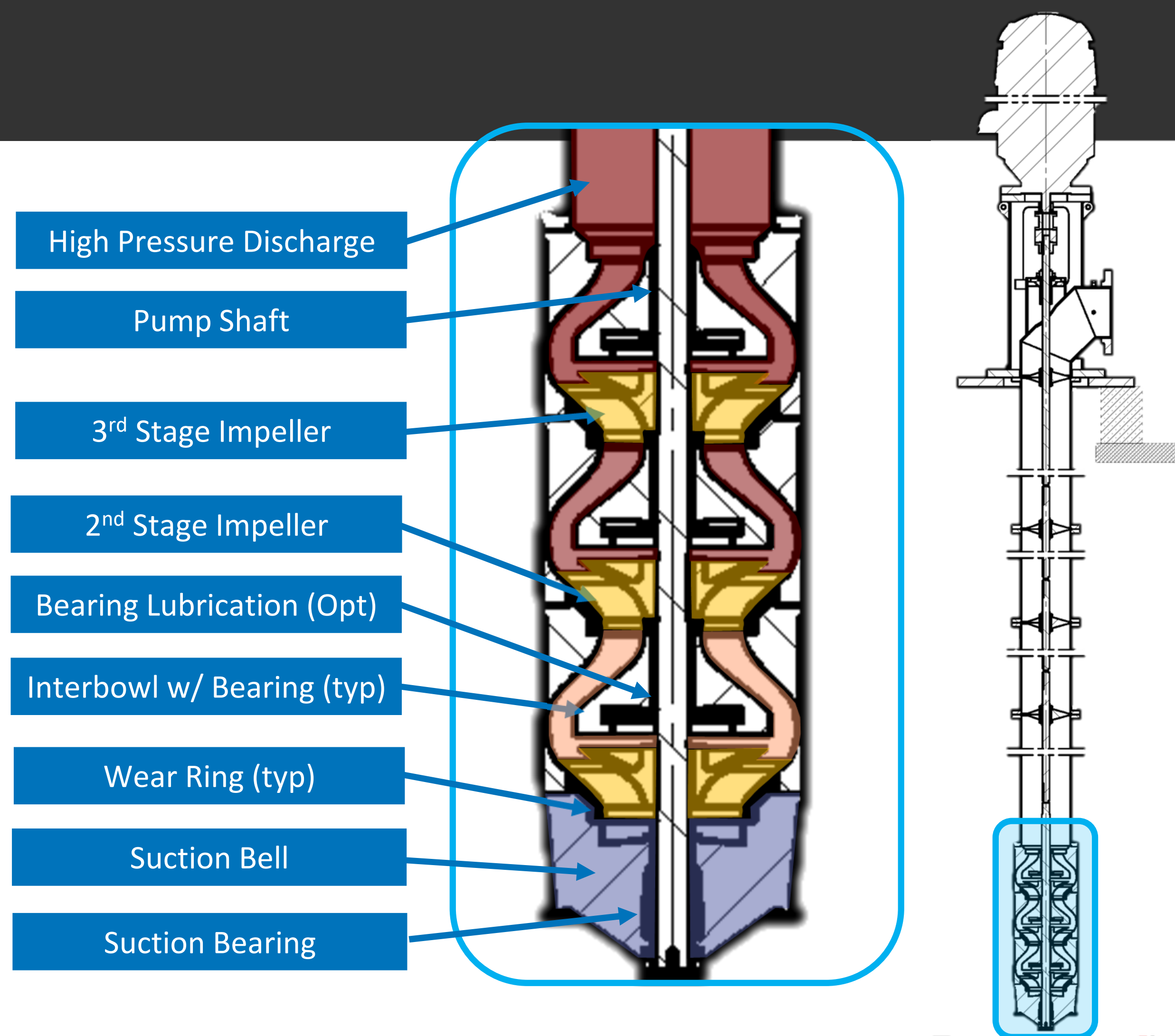
Pump Components

- Multi-stage impeller and volute assembly



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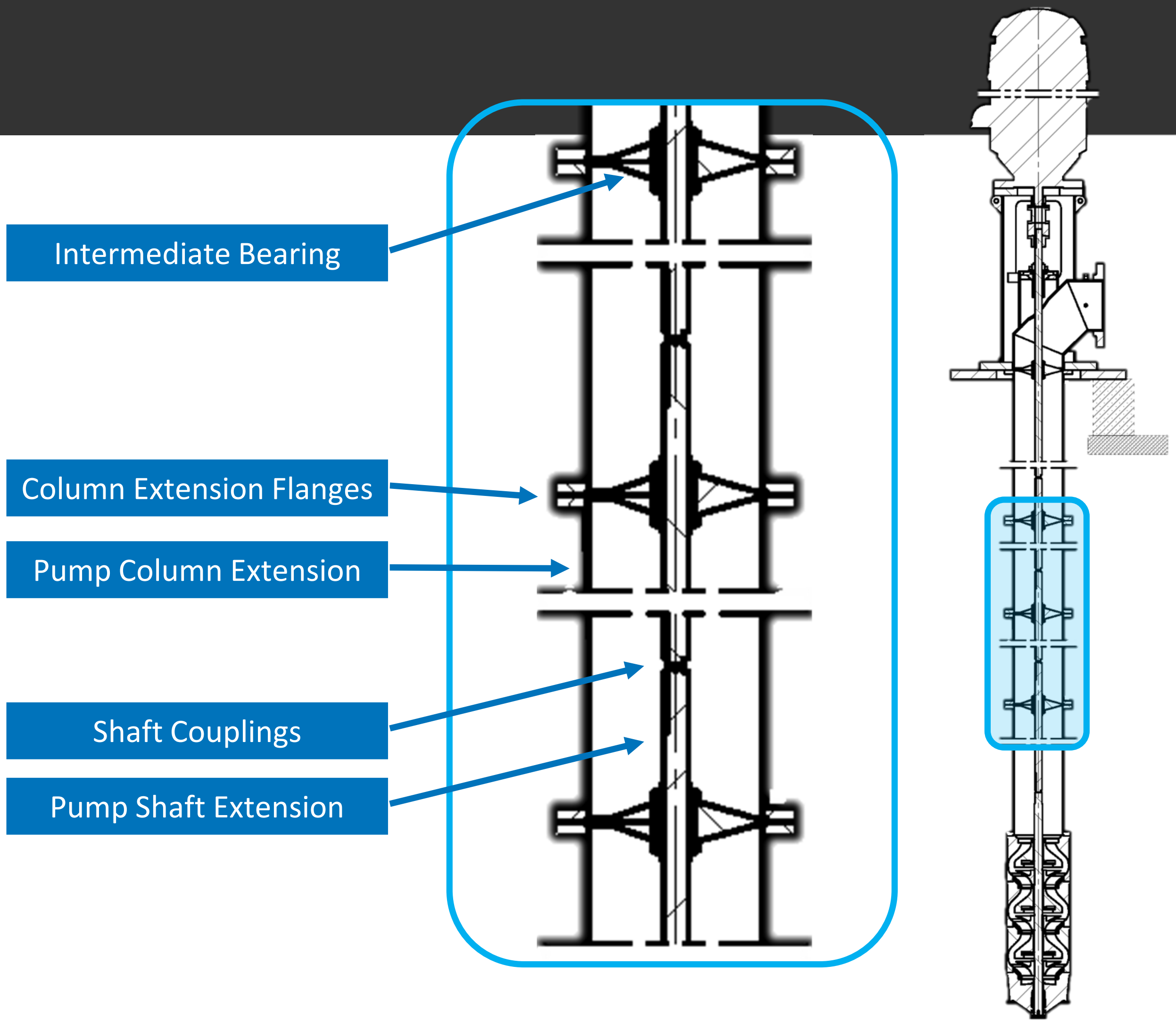
VT PUMP OVERVIEW

Pump Components

- Multi-stage impeller and volute assembly
- Column and shaft extensions



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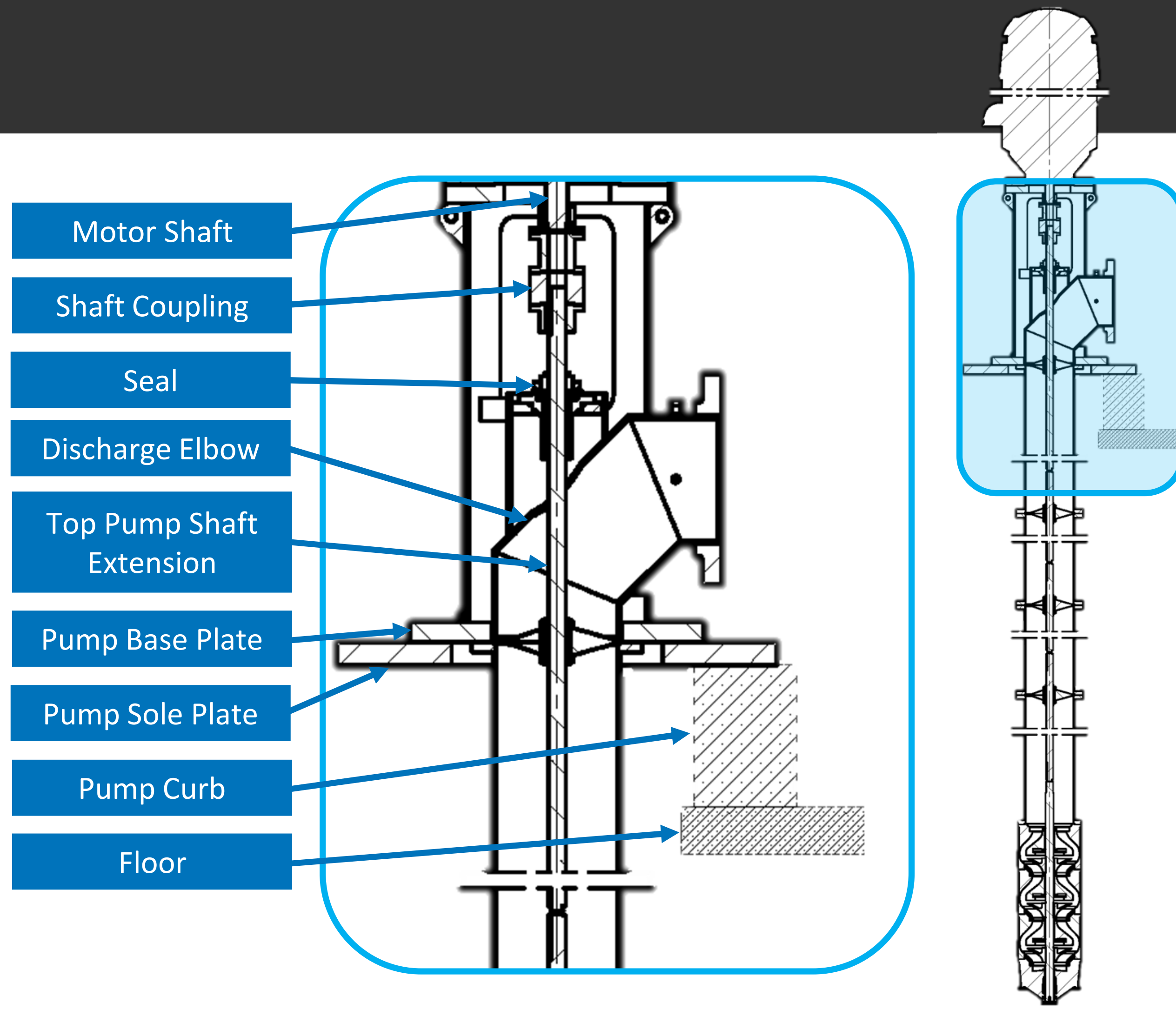
VT PUMP OVERVIEW

Pump Components

- Multi-stage impeller and volute assembly
- Column and shaft extensions
- Pump base



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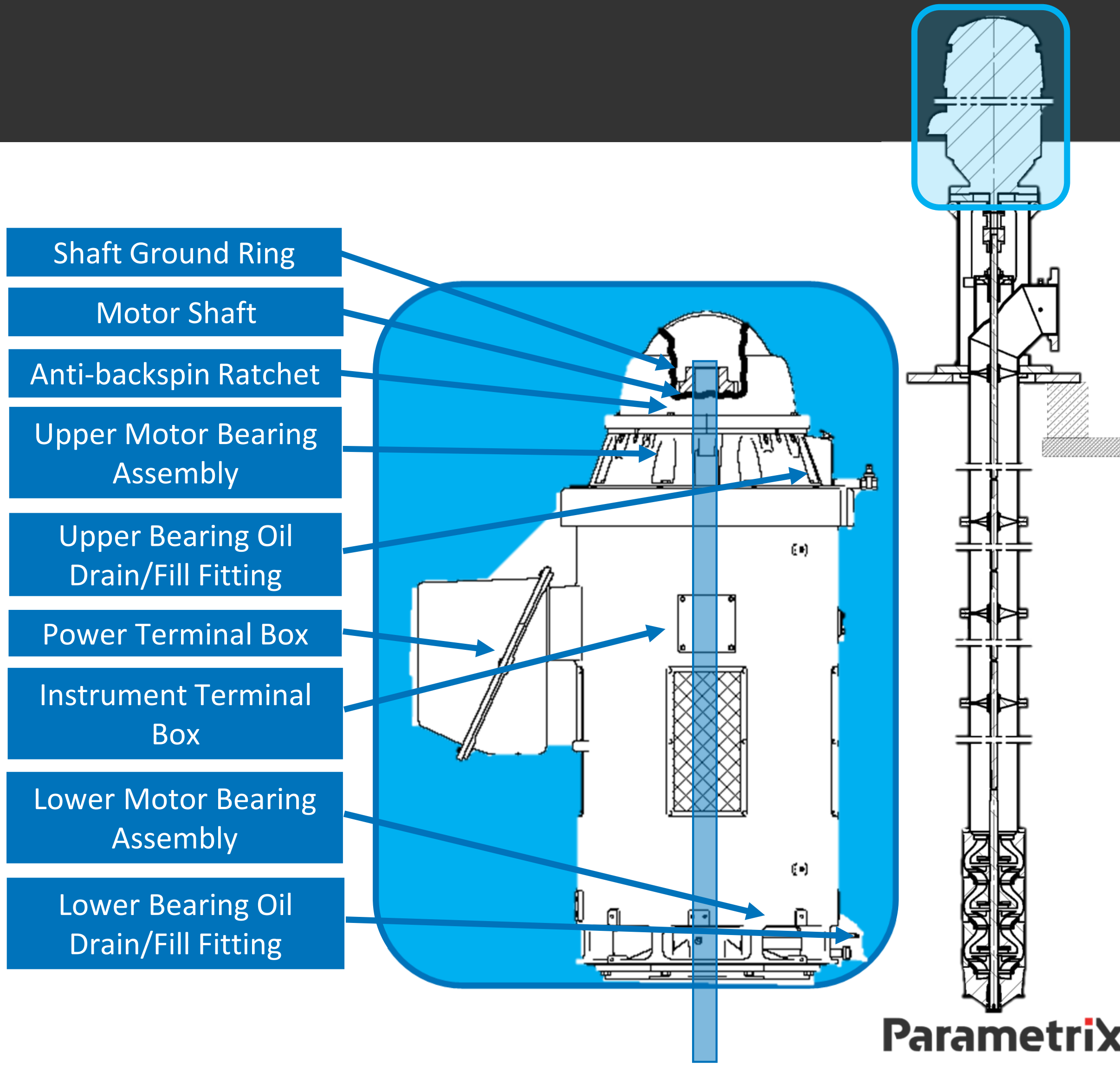
VT PUMP OVERVIEW

Pump Components

- Multi-stage impeller and volute assembly
- Column and shaft extensions
- Pump base
- Motor



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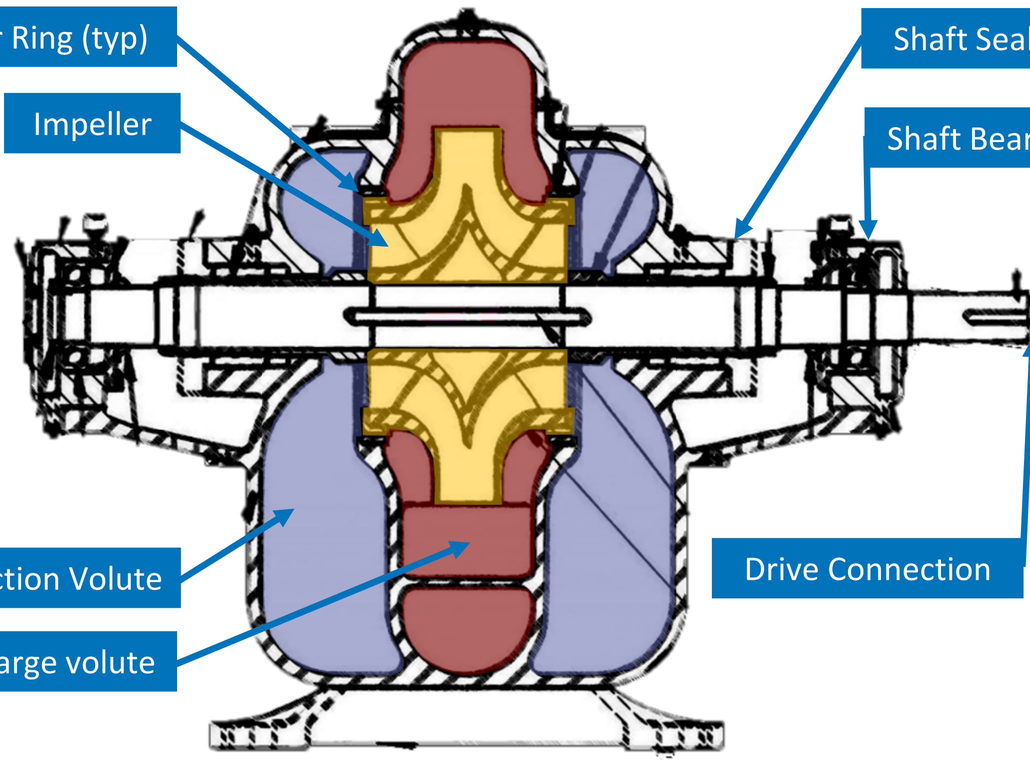
SPLIT CASE PUMP BREAKDOWN

- High efficiencies and low HPSHr
- Shaft and seal loads are balanced
- Larger footprint, smaller height requirements



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NSF 61 COMPLIANCE VS. CERTIFICATION

NSF 61: *Drinking Water System Components*

Primarily focused on materials in contact with water

NSF 61 COMPLIANCE

- US EPA – Reduction in Lead Drinking Water Act (amendment to Safe Drinking Water Act)
- Designed for potable water
- All <u>components</u> meet NSF 61
- (OAR) 333-061-0050 || (WAC) 246-290-220 || (IDAPA) 58.01.08.501

NSF 61 CERTIFICATION

- Applies to pump assembly
- 3rd party certification
- Limits available pumps and features
- Must use spare parts matching original certification

NSF 61 COMPLIANCE VS. CERTIFICATION

NSF 61: *Drinking Water System Components*

Primarily focused on materials in contact with water

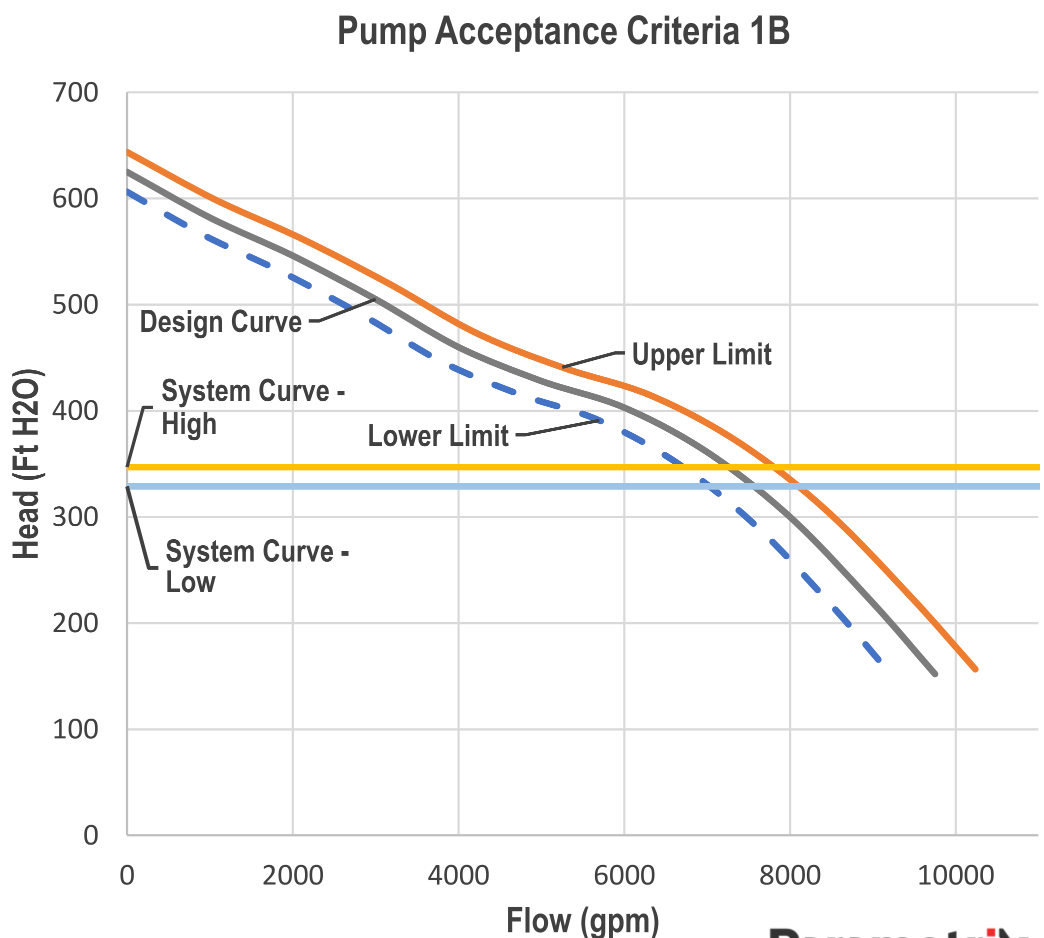
	NSF 61 COMPLIANCE: OEM	NSF 61 COMPLIANCE: OEM Alt Parts	NSF 61 COMPLIANCE: 3RD PARTY	NSF 61 CERTIFICATION: OEM	NSF 61 CERTIFICATION: OEM Alt Parts	NSF 61 CERTIFICATION: 3RD PARTY
Pump Internals	✓	✓	✓	✓	☐	☐
Motor, shaft coupling, etc.	✓	✓	✓	✓	✓	✓

ACCEPTANCE GRADES

ANSI/HI 14.6-2022
Pump Acceptance Tests

Table 14.6.3.4 — Pump test acceptance grades and corresponding tolerance band

Test parameter	Guarantee requirement	Grade	Grade 1			Grade 2		Grade 3
		Δ t_Q	10%			16%		18%
		Δ t_H	6%			10%		14%
			Acceptance grade					
		Symbol	1B	1E	1U	2B	2U	3B
Rate of flow	Mandatory	t_Q (%)	± 5%	± 5%	0% to + 10%	± 8%	0% to +16%	± 9%
Total head	Mandatory	t_H (%)	± 3%	± 3%	0% to + 6%	± 5%	0% to +10%	± 7%
Power	Optional[a] (either/or)	t_P (%)	+ 4%	+ 4%	+ 10%	+ 8%	+ 16%	+ 9%
Efficiency[b]		t_η (%)	− 3%	− 0%	− 0%	− 5%	− 5%	− 7%



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ACCEPTANCE GRADES

ANSI/HI 14.6-2022

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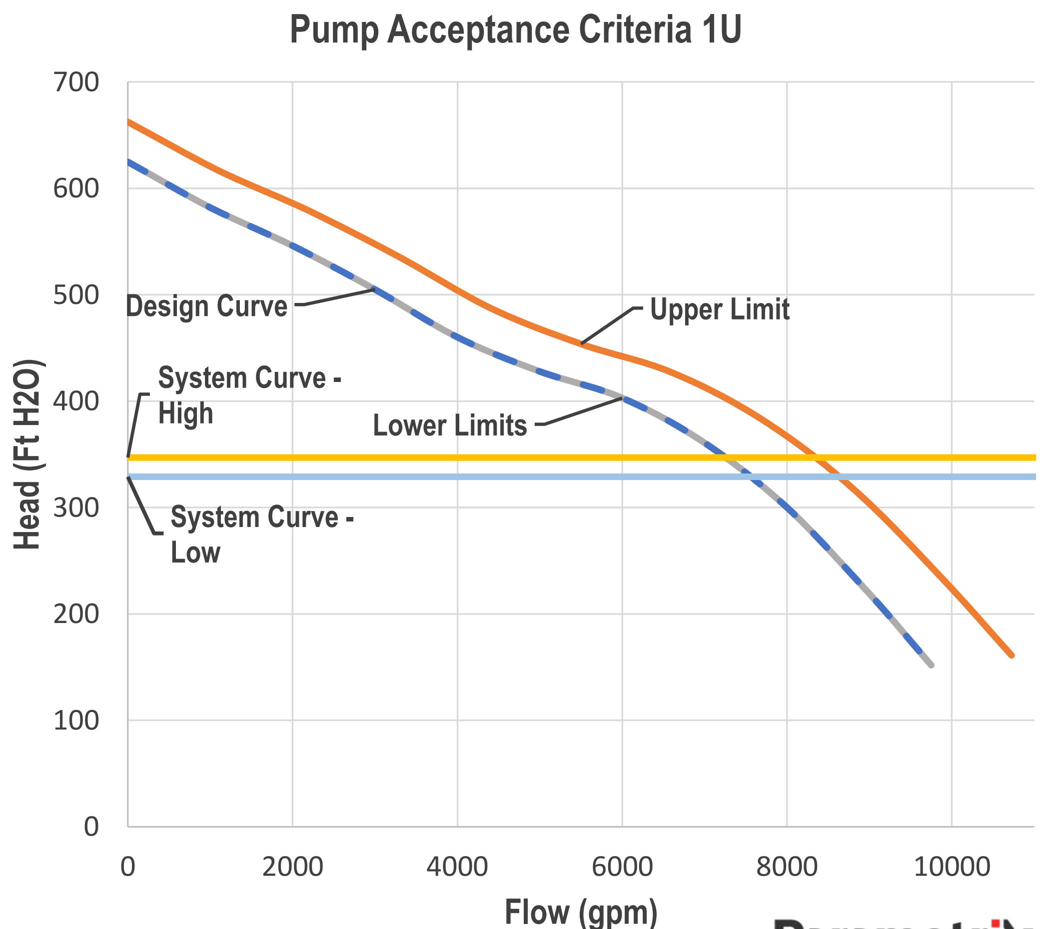

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ACCEPTANCE GRADES

Application		Rated shaft power of pump	
		> 10 to 100 kW (13 to 134 hp)	> 100 kW (134 hp)
Municipal water and wastewater		2B	1B
Building trades and HVAC		2B	1B
Electric power industry		1B	1B
Oil and gas industry	API pumps	1B	1B
	Pipeline	1B	1B
	Water injection	Not applicable	1B
Chemical industry		2B	2B
Cooling tower		2B	2B
Pulp and paper		2B	2B
Slurry		3B	3B
General industry		3B	2B
Dewatering, drainage, and irrigation		3B	2B
Pumps not listed above		3B	2B

NOTE: This table only applies to situations where the purchaser and manufacturer have agreed to a guarantee point, but no test acceptance grade has been specified.

Other specified duty points, including their tolerances, shall be per separate agreement between the manufacturer and purchaser. If other specified duty points are agreed on, but no tolerance is given for these points, then the default acceptance grade for these points shall be grade 3B.

Testing and Inspection

Qty	Description
1	**Testing and Inspection**
	Performance Testing Details
	Test Acceptance Criteria: ANSI/HI 14.6 Grade 1U
	Test Tolerance: Flow = -0/+10%, Head = -0/+6%, Power = -0/+10%, Efficiency -0/+0%
	Performance Test Options
	Complete Unit Test With Job Driver - 1 units

Capacity	: 7150.0 USgpm
Head	: 350.00 ft
Density / Specific gravity	: - / 1.000
Pump speed	: 1780 rpm
Ns / Nss	: - / 11810 (US units)
Test tolerance	: ANSI/HI 14.6 Grade 1B

Take Away: Failure to account for tolerances can cause under/over performance, incorrect pump submission, inadequate electrical capacity, or system damage.

TRANSIENT AND WATER HAMMER

- Hydraulic Transient = Water Hammer
  - A sudden change in pressure that travels through a piping system as a high-speed wave
  - Caused by an abrupt change in flow rate
  - Pressure surge
- Vacuum (Negative) Pressure
  - When the hydraulic grade line (HGL) drops more than 14.7 psi/33.9 ft below pipe centerline
  - Water boils, dissolved air pulled from solution
  - Vapor cavity

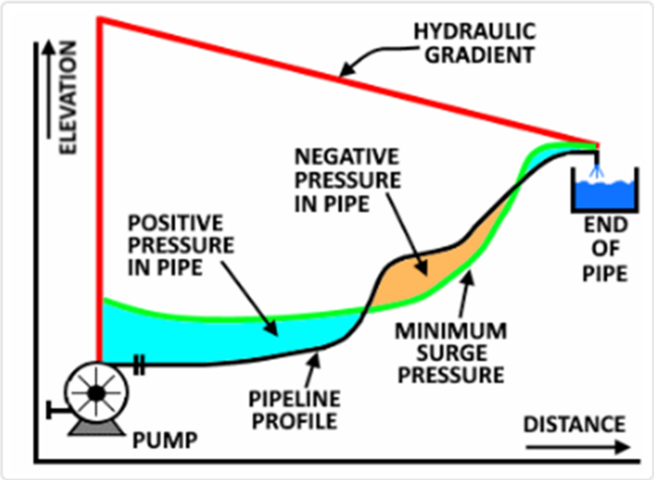
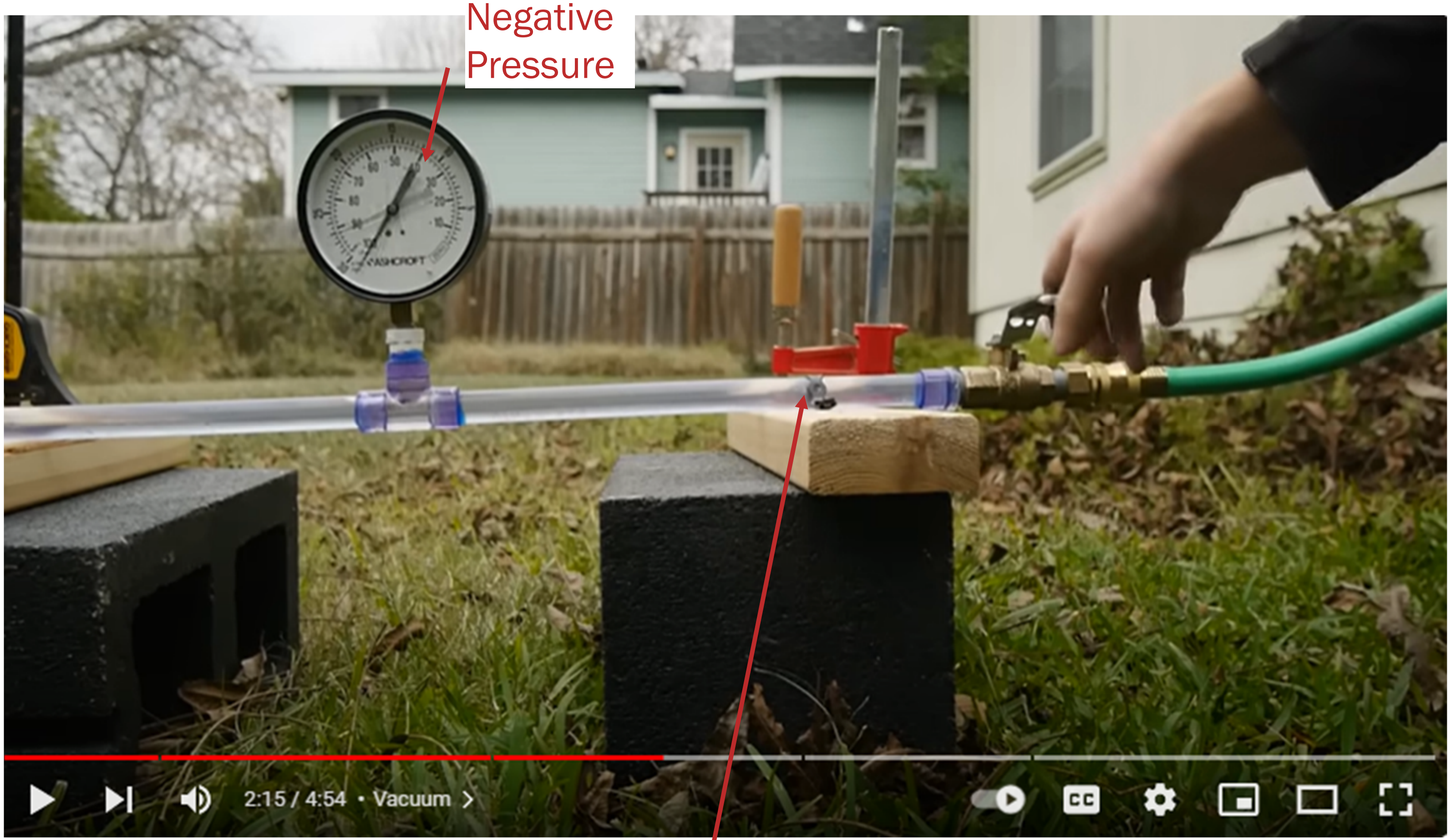


Image: https://www.flo-dyne.net/pages/12_Surge_Analysis.php

VAPOR CAVITY FORMATION



https://www.youtube.com/PracticalEngineeringChannel

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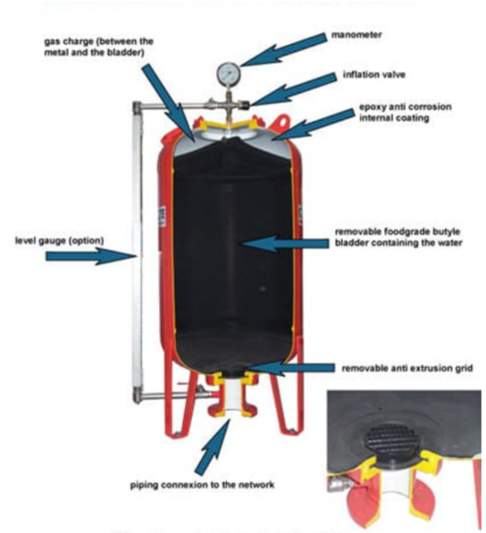
VAPOR CAVITY FORMATION AND LOW-PRESSURE DAMAGE

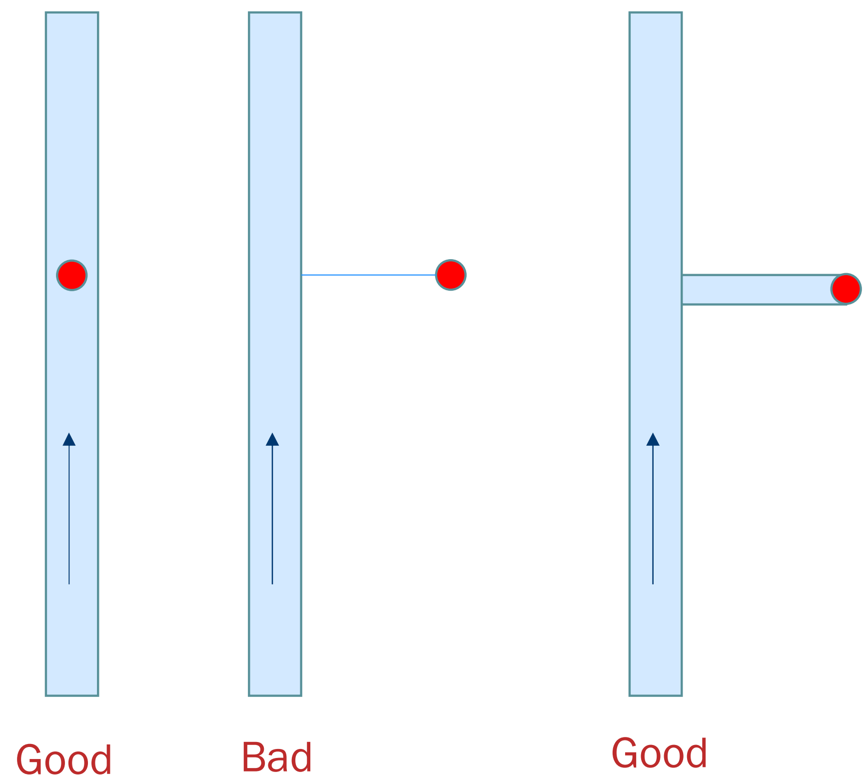
- When is it likely?
  - fire flow + power outage
- Potential damage?
  - Pipe failure, immediate/long term
  - Gasket damage
- How to mitigate?
  - Limit pressure drop in the pipeline to -10 psi

    Add vacuum relief valves, surge tanks



VAPOR CAVITY FORMATION AND LOW-PRESSURE DAMAGE

- Laterals for ARV/VRV impact the protection capacities
  - Length and Diameter



– WHEN DO YOU NEED TRANSIENT ANALYSIS – CASE STUDY

- Tacoma Water – McMillian Reservoir Case Study
  - History of water hammer?
  - Changes in pipe alignment/profile and size?
  - Changes to flow rates?
  - Changes to valve closure and/or pump control strategies?

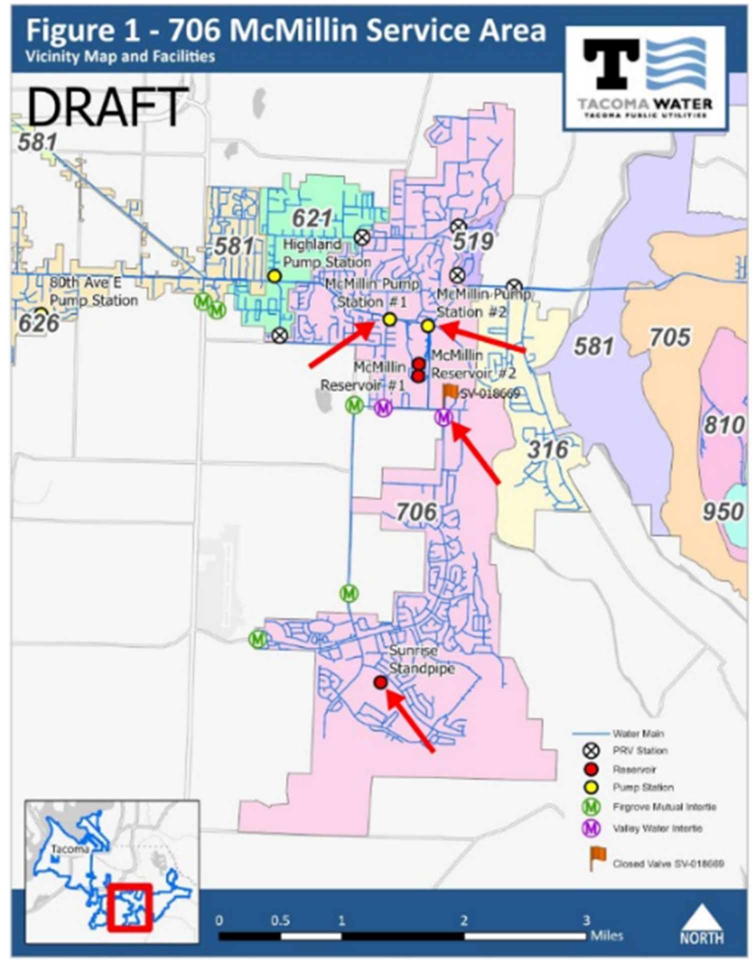
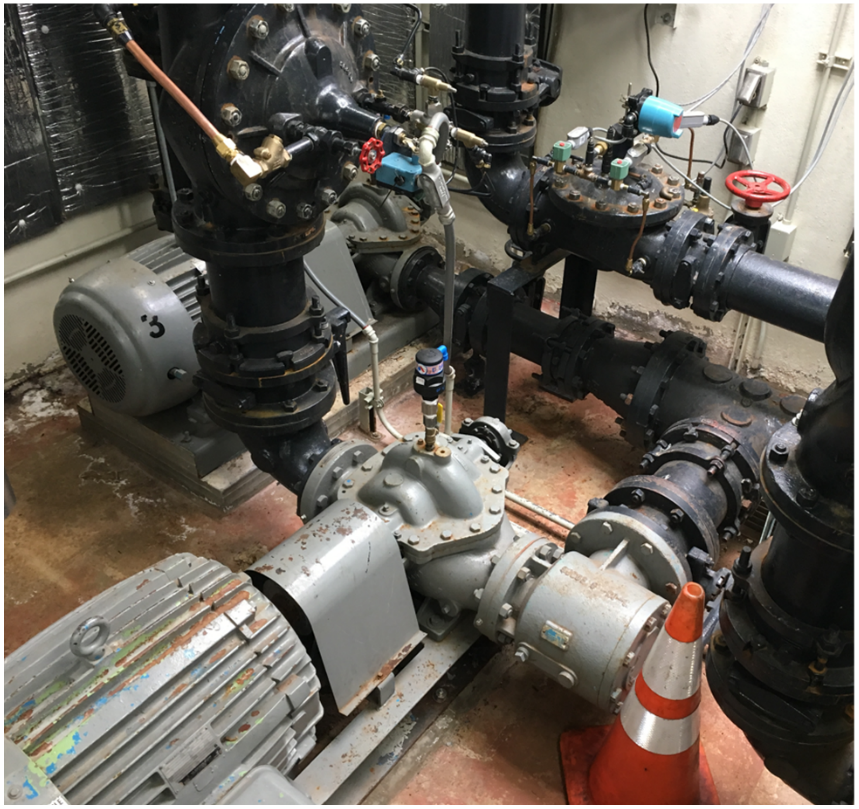


Figure 1. 706 McMillin Service Area

– WHEN DO YOU NEED TRANSIENT ANALYSIS – CASE STUDY

- Somerset 2 Booster PS - Case Study
  - History of water hammer?
  - Changes in pipe alignment/profile and size?
  - Changes to flow rates?
  - Changes to valve closure and/or pump control strategies?



TRANSIENT ANALYSIS – CASE STUDIES

- Bremerton FM Network Failure Analysis

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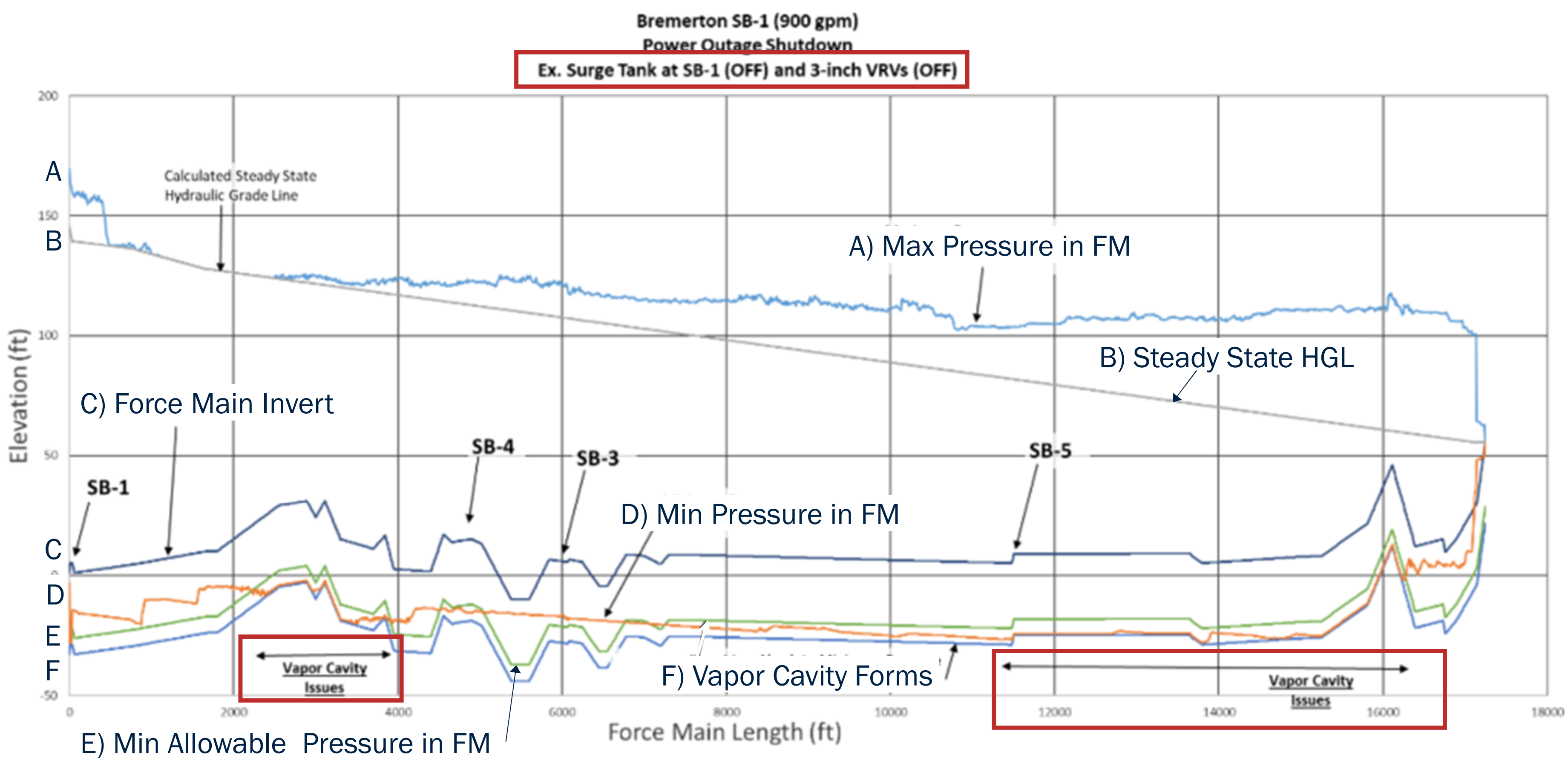
TRANSIENT ANALYSIS – CASE STUDIES



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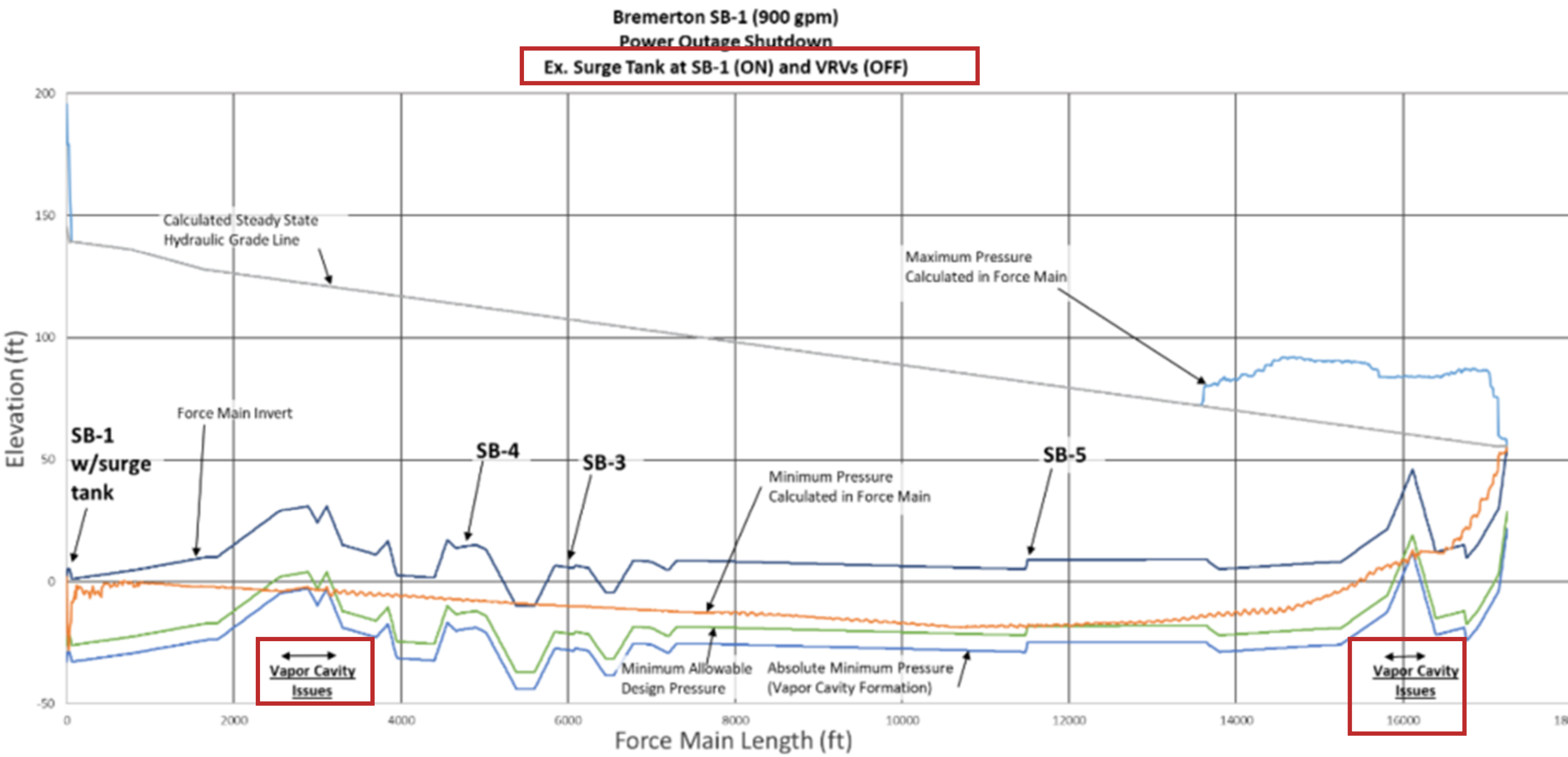
TRANSIENT ANALYSIS – CASE STUDIES



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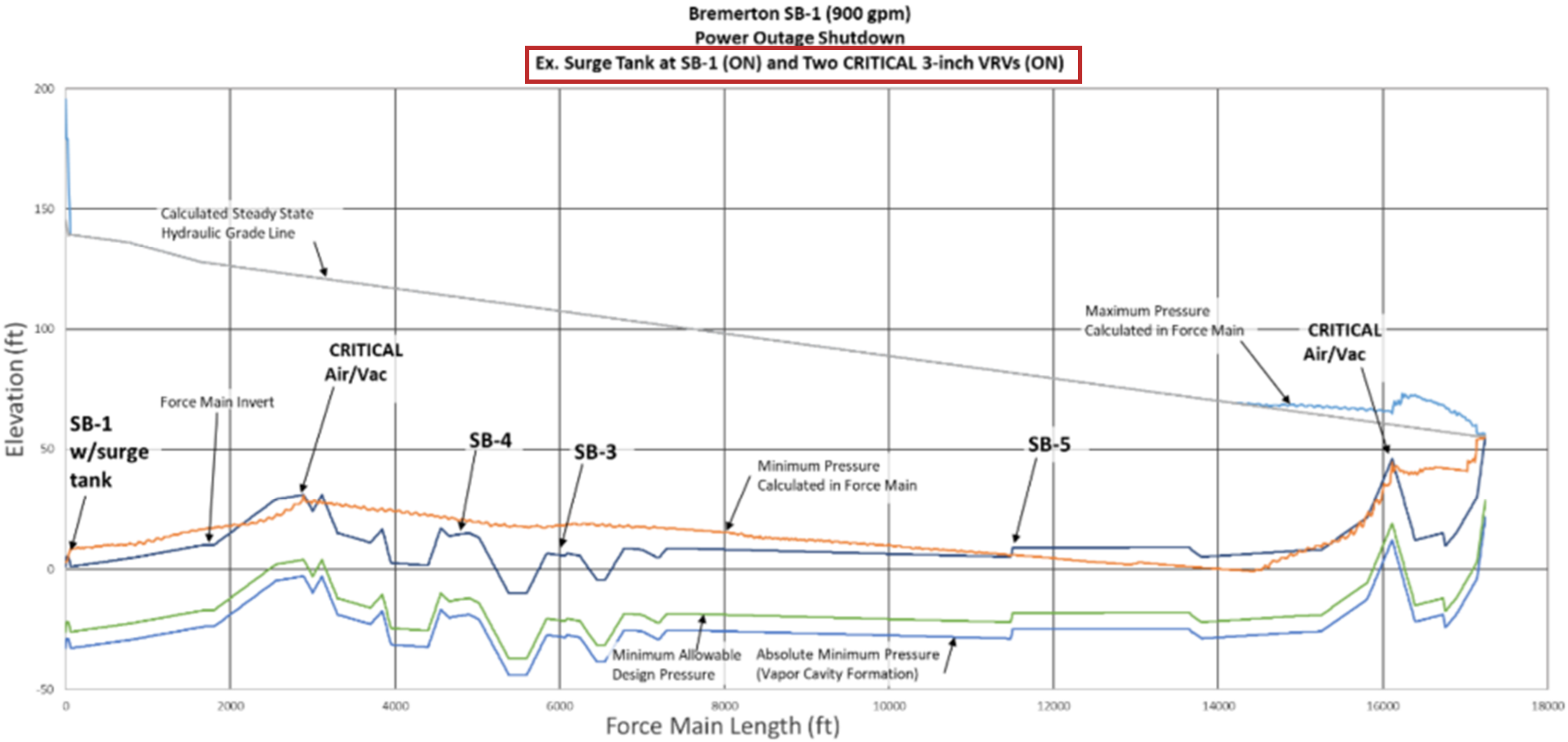
TRANSIENT ANALYSIS – CASE STUDIES



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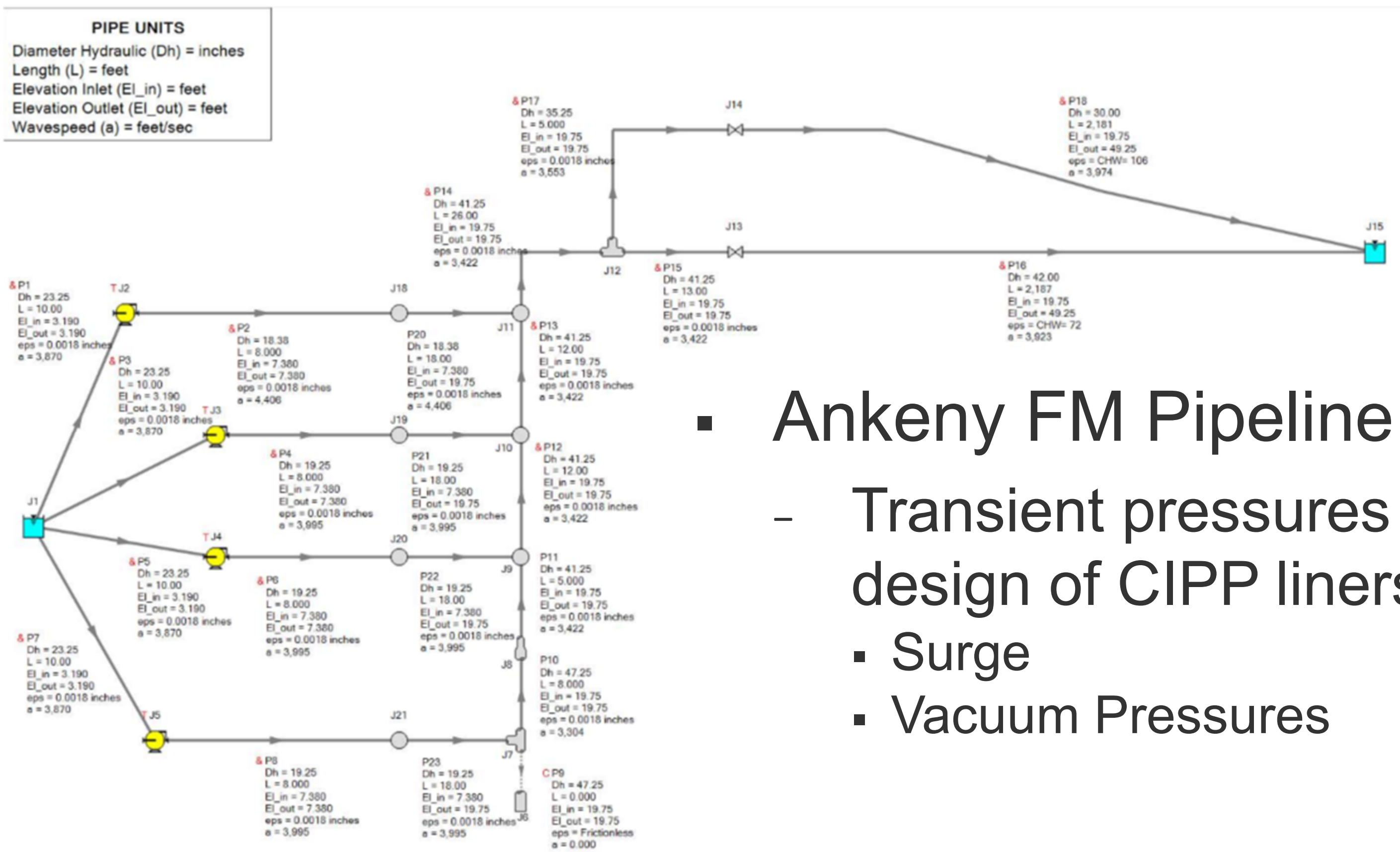
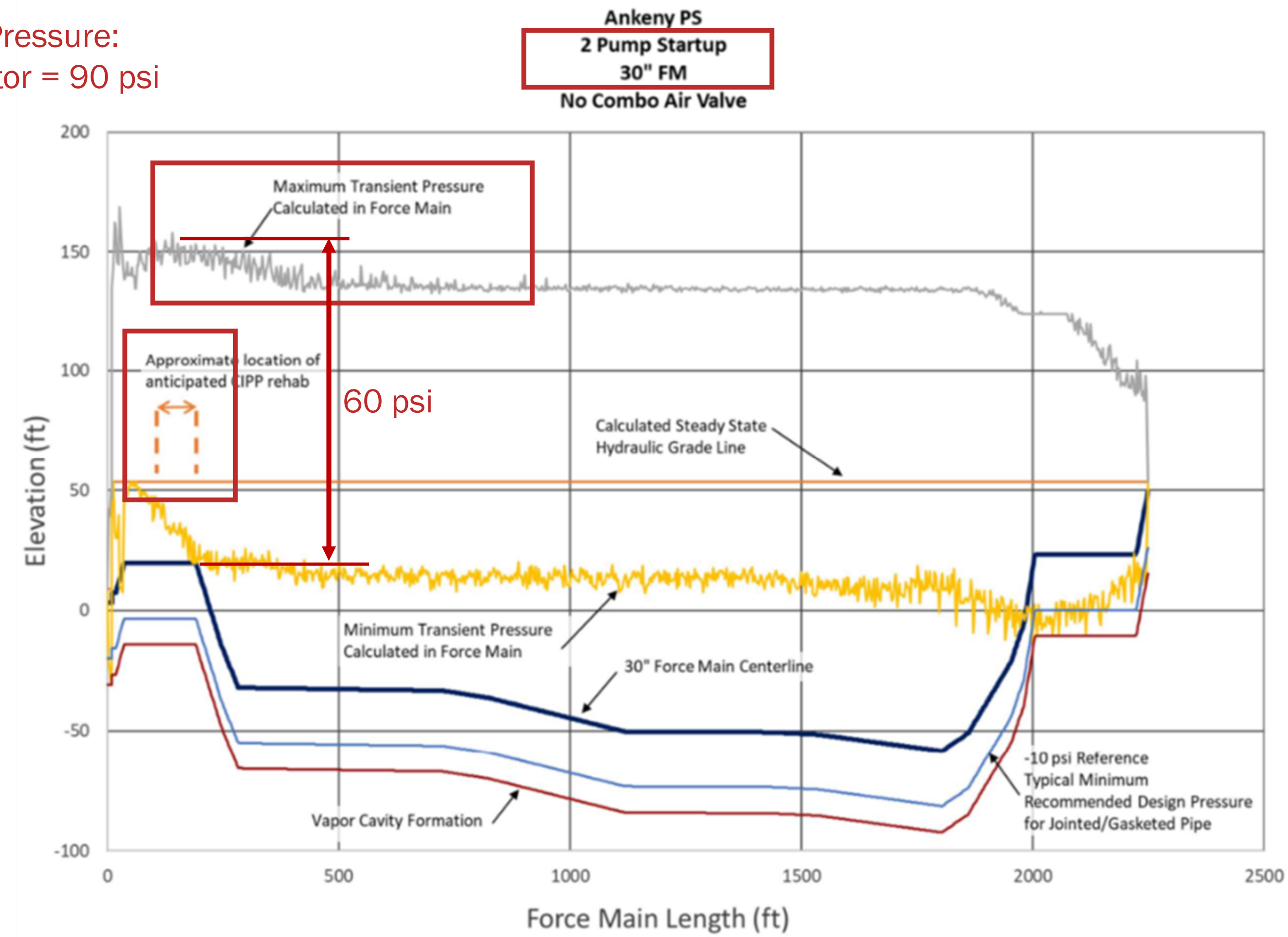
TRANSIENT ANALYSIS – CASE STUDIES



- Ankeny FM Pipeline Rehab
  - Transient pressures impact structural design of CIPP liners
    - Surge
    - Vacuum Pressures

TRANSIENT ANALYSIS – CASE STUDIES

CIPP Maximum Surge Pressure:
60 psi x 1.5 Safety Factor = 90 psi



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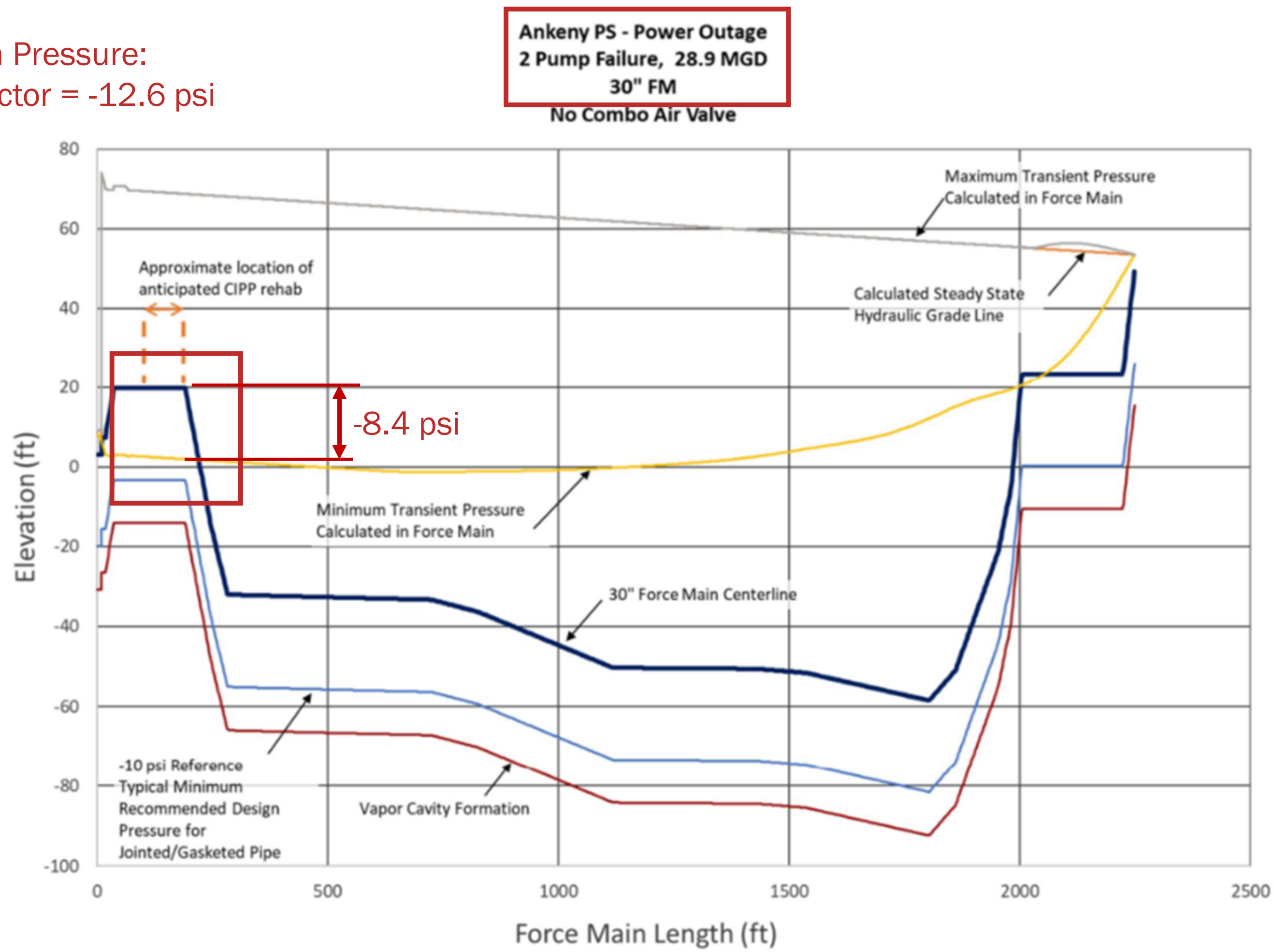
TRANSIENT ANALYSIS – CASE STUDIES

CIPP Minimum Vacuum Pressure:
-8.4 psi x 1.5 Safety Factor = -12.6 psi



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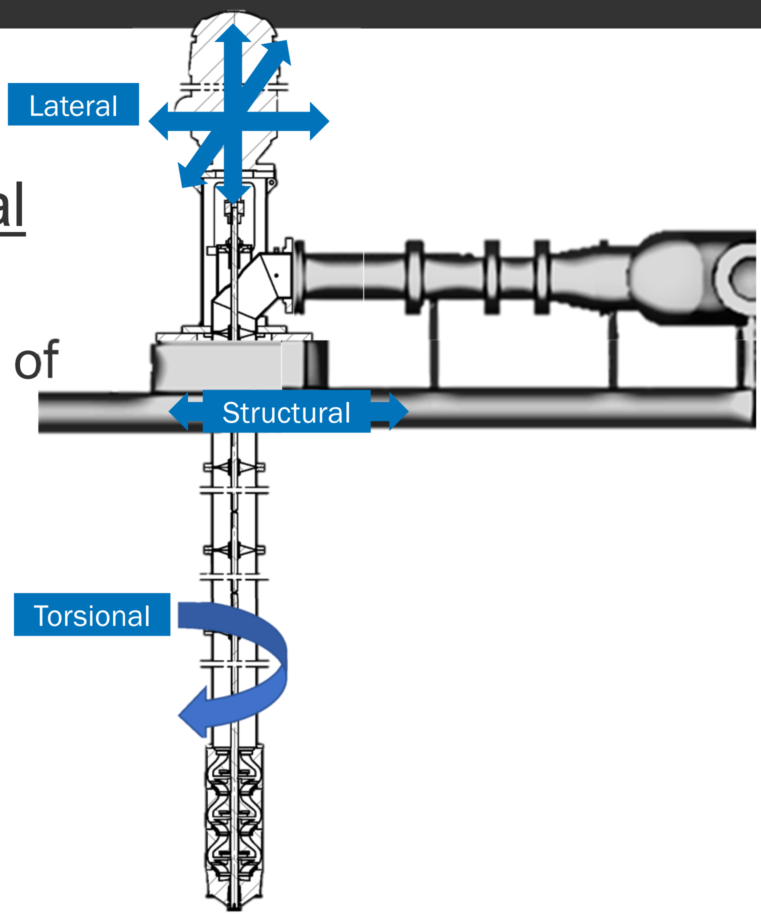
VIBRATION ANALYSIS

ANSI/HI 9.6.8: Lateral Rotor Dynamic, Torsional Rotor Dynamic and Structural Analyses

- Performing these analyses reduce the risk of vibration and reliability problems



Case Study: JWC Finished Water PS No, 2

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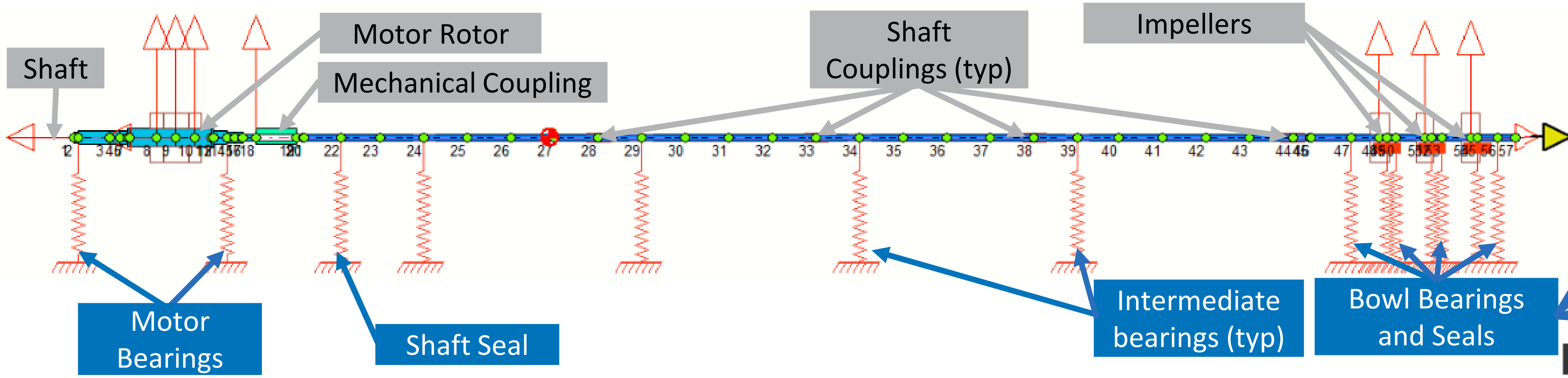
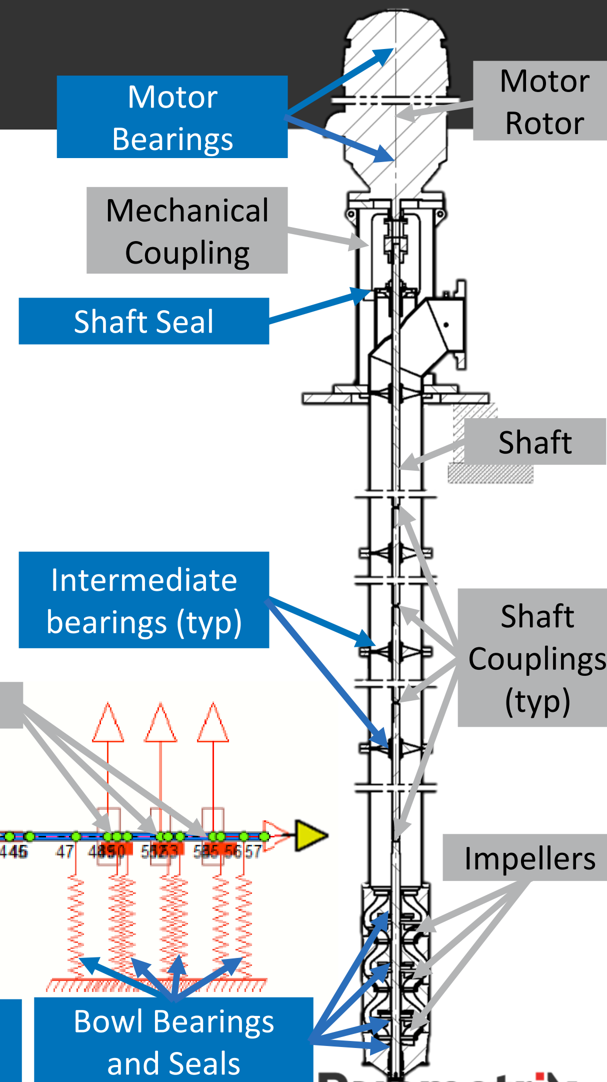
LATERAL ROTODYNAMIC ANALYSIS

Lateral Vibration related issues:

- Accelerated wear at wear rings
- Rubs at internal clearance locations
- Accelerated bearing wear
- Excitation of critical frequencies





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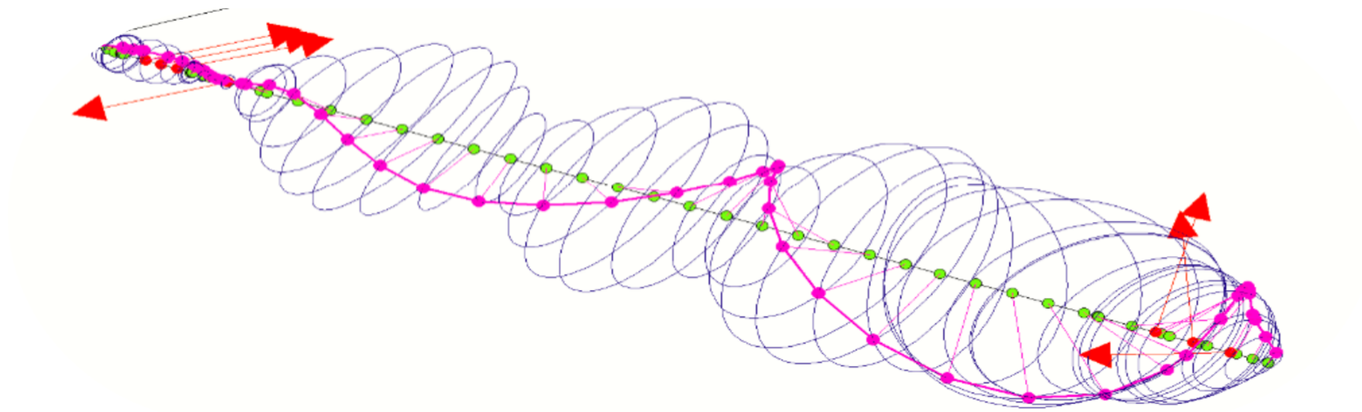
LATERAL ROTODYNAMIC ANALYSIS

Lateral Vibration related issues:

- Accelerated wear at wear rings
- Rubs at internal clearance locations
- Accelerated bearing wear
- Excitation of critical frequencies

Lateral Analysis

- Performed on the *complete train* (pump, driver, couplings, and gears)



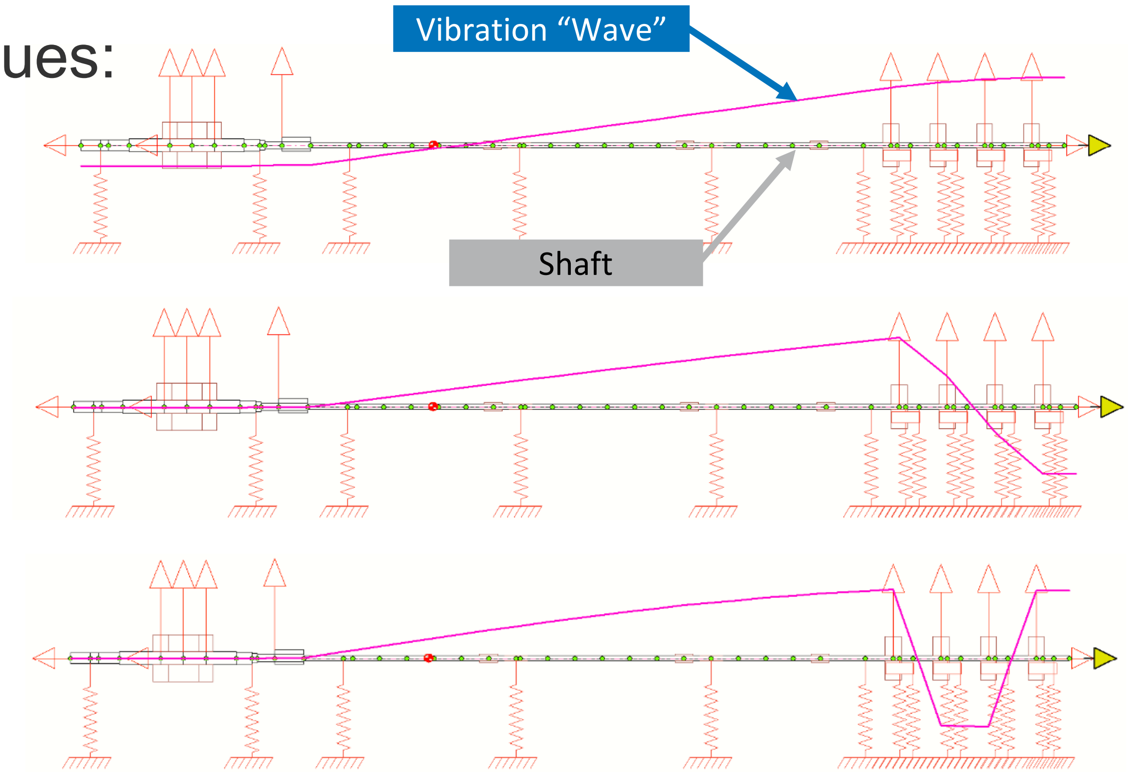
TORSIONAL ROTODYNAMIC ANALYSIS

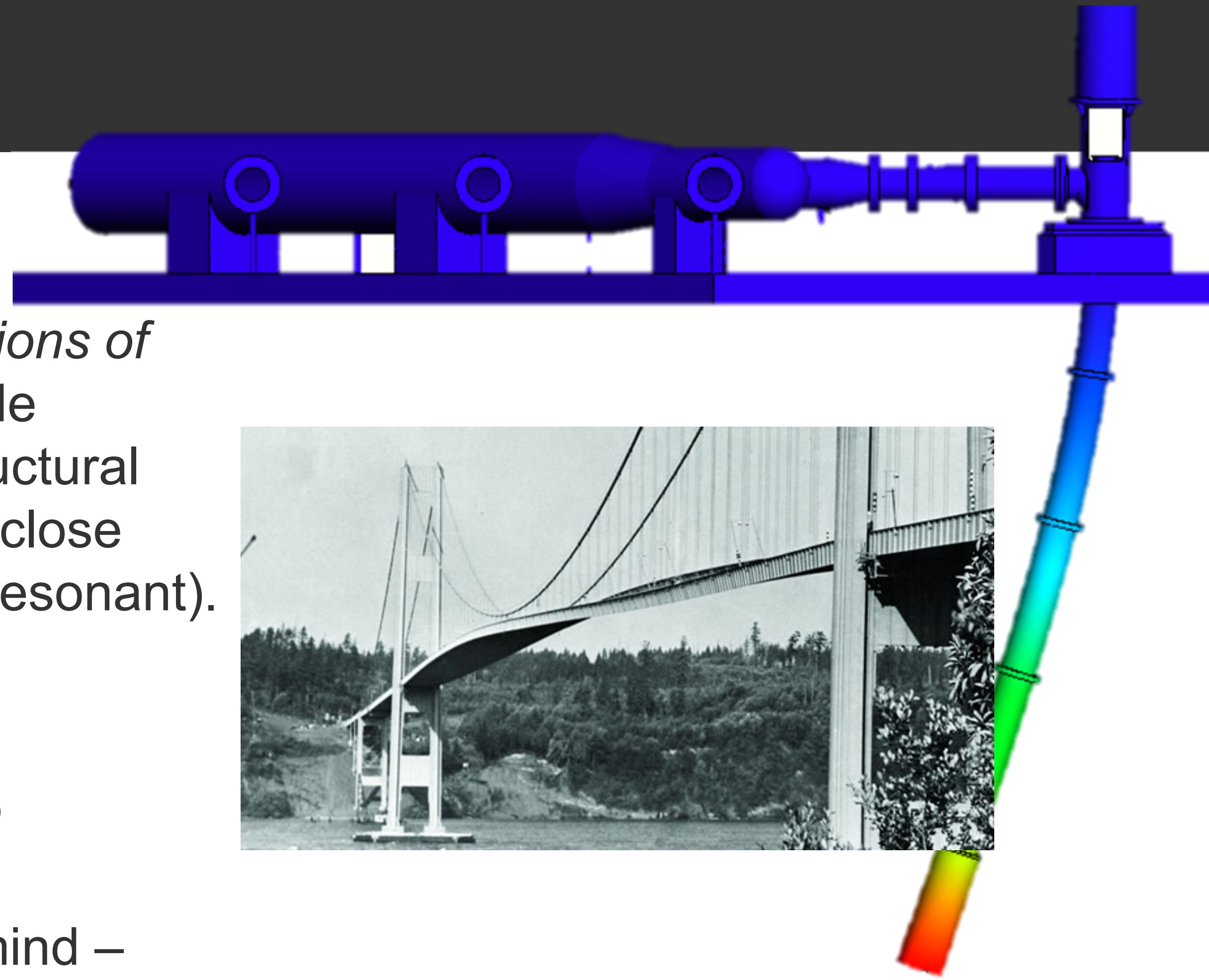
Torsional Vibration related issues:

- Damaged couplings
- Gear wear, noise
- Shaft fatigue or failure

Torsional Analysis

- Performed on the *complete train* (pump, driver, couplings, and gears)





Structural Analysis

- Performed to *non-rotating portions of the pump and system* to provide reasonable assurance that structural natural frequencies will not be close enough to typical excitations (resonant).
  - Determine reed frequency
  - Identify and ideally shift any frequencies within the pump operating range
  - Keep structure stiffness in mind – may be able to avoid via “bump test” of existing structure

REQUIREMENT FOR VIBRATION ANALYSIS

ANSI/HI 9.6.8: Lateral Rotodynamic, torsional rotordynamic and structural analysis

Rotodynamic Pumps – Guideline for Dynamics of Pumping Machinery:

- Uncertainty (U)
  - Blade pass (vanes), coupling frequency
  - Motor size and speed
- Risk (R)
- "RUN" – Risk * Uncertainty

Note 1: It is recommended that the user of this document be acquainted with the document's contents prior to using this matrix.

Note 2: The vendor and user should agree on the suggested level of analysis as determined in step 4.

Note 3: Compose the contract specifications using applicable portions of Appendices E and F using the level of analysis determined.

Step 1 - Determine and enter uncertainty value "U" from Table 9.6.8.3.1 for each type of analysis, lateral, torsional, and structural.		
Enter sum from Table 9.6.8.3.1, Lateral rotor dynamic analysis	Enter sum from Table 9.6.8.3.1, Torsional rotor dynamic analysis	Enter sum from Table 9.6.8.3.1, Structural dynamic analysis

Step 2 - Determine and enter risk value "R" from suggested values below.			Enter selecte R value
RISK NUMBER, R	Unknown, new design with no field experience.	20	
	Significant modifications to standard product or similar design - no experience in field.	10	
	Minor modifications to standard product or similar design proven in field.	4	
	Identical or standard product, proven field history.	2	

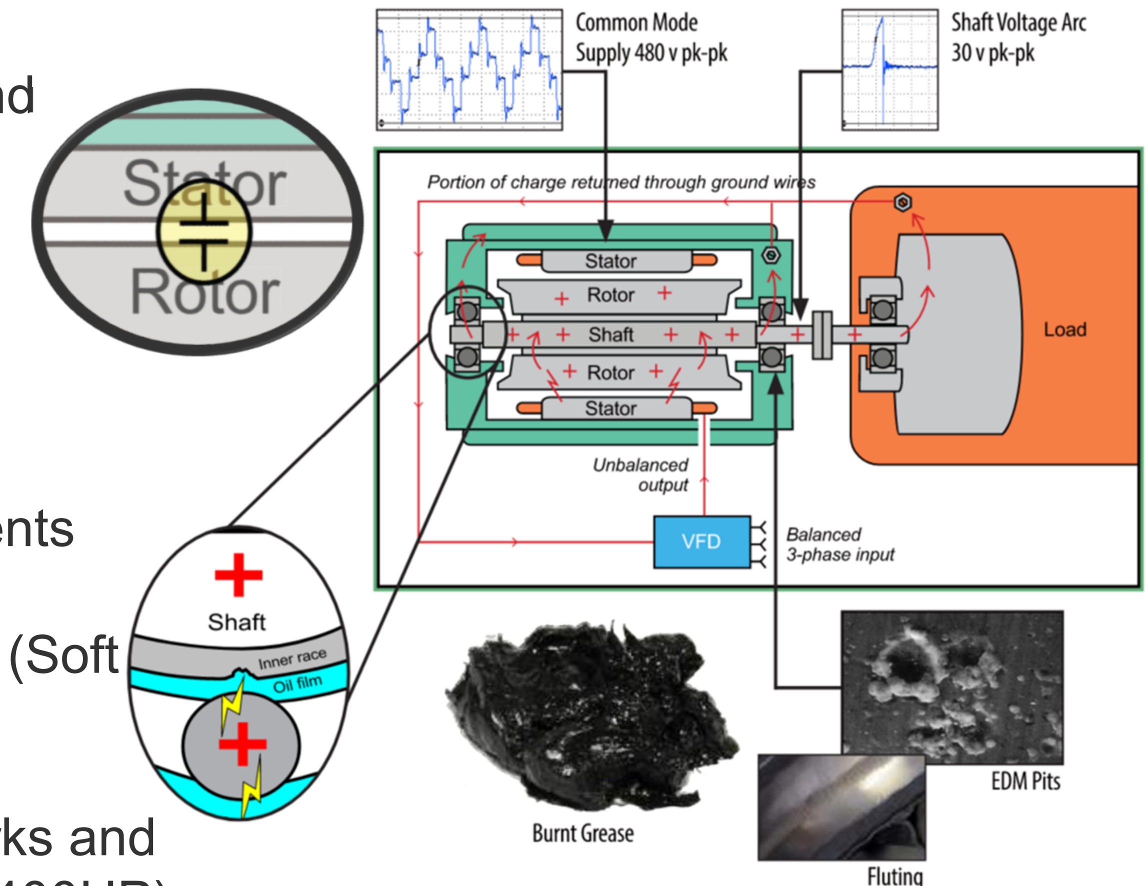
Step 3 - Multiply the "R" values from step 2 times the risk value "U" selected in step 1 for each type of analysis. These are the "RUN" values.		
Lateral	Torsional	Structural
Products of R x U, or RUN numbers		

Step 4 - Using the calculated "RUN" value from step 3 for each analysis type (lateral, torsional, or structural), determine the suggested level of analysis for each type of analysis from the guidelines below.	
RUN value from step 3	Suggested level of analysis
≤ 15	None Required
> 15, ≤ 20	Level 1
> 20, ≤ 50	Level 2
> 50, ≤ 160	Level 3
> 160	Level 3 +Validation*

ELECTRICAL CONSIDERATIONS

NEMA MG-1 vs “VFD Rated”

Safety factors, starting conditions, and limitations



Shaft Grounding Rings

Protect from:

1. Capacity EDM Currents (VFDs)
2. High Frequency Circulating Currents (VFDs)
3. Line Current Circulating Currents (Soft starts, etc)

<u>Case Study</u>: Portland BES, Headworks and WWIPS PS VFD Upgrades (200HP, 400HP)

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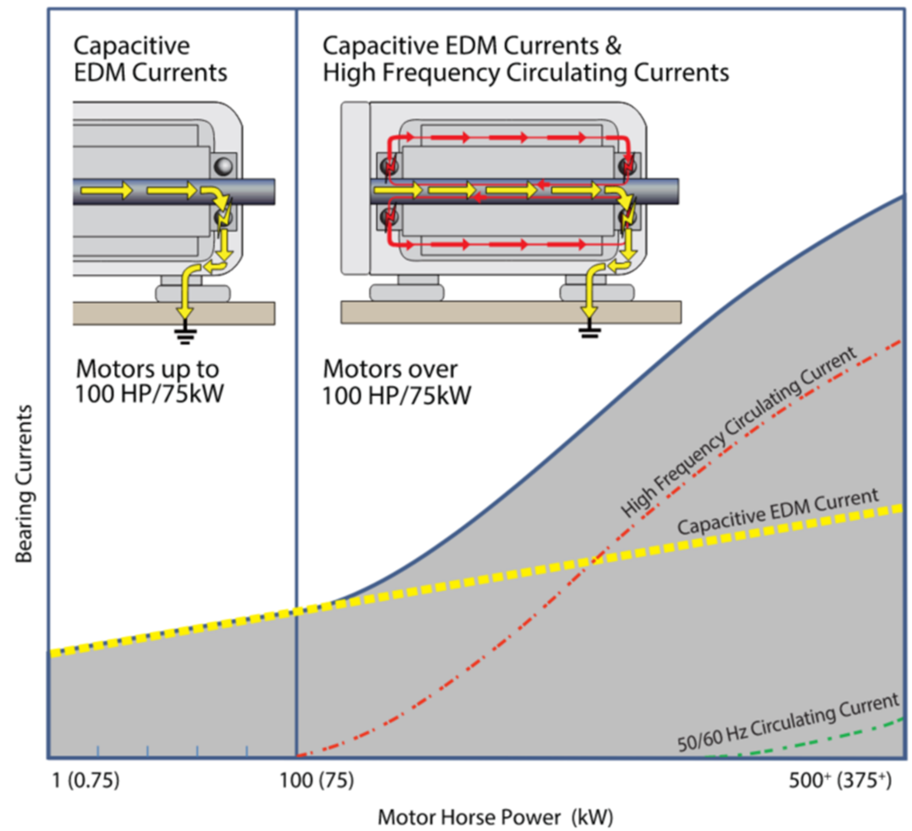

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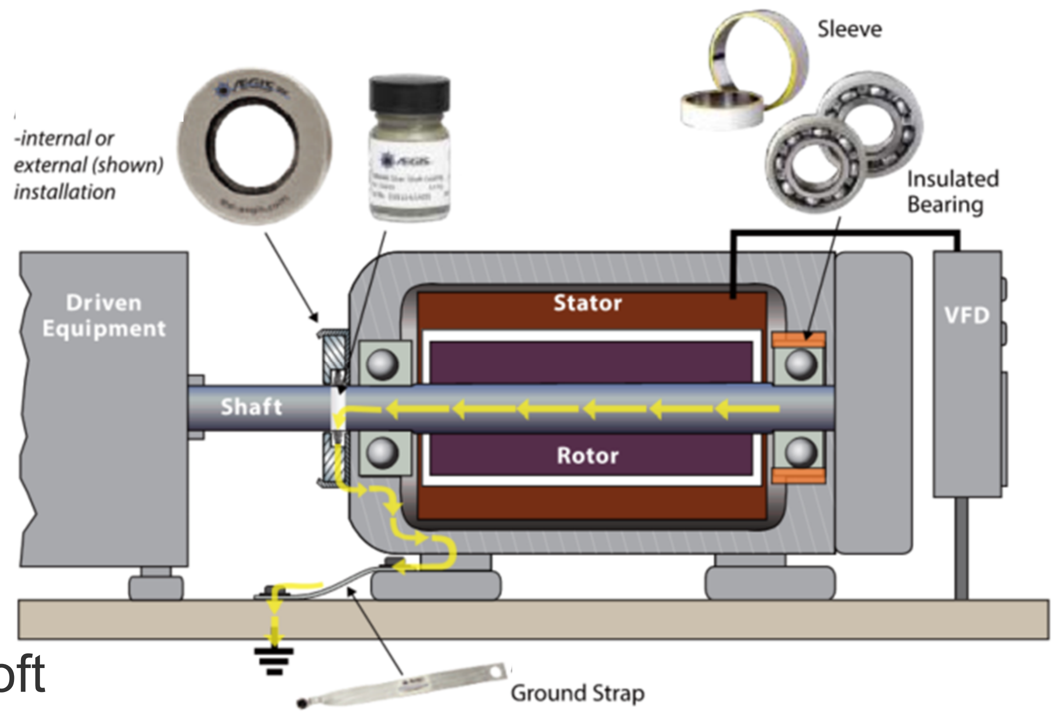

Case Study: Portland BES, Headworks and WWIPS PS VFD Upgrades (200HP, 400HP)

INSTRUMENTATION AND CONTROLS

Temperature Monitoring
Bearing and winding monitoring

Vibration Monitoring
Point Monitoring vs Continuous Monitoring

Power Monitoring
Load imbalances, temperature correction, ect.

CLOSING REMARKS

- Large Pumps (200+ HP) have unique considerations
- Standards such as NSF 61, HI 9.8, HI 9.6.8, HI 14.6, and NEMA MG-1 provide lot of specific guidance
- Still require detailed conversations with both manufacturers and clients
- Leverage other municipalities experiences, consultants, manufacturers – the water COMMUNITY! (us?)

THANK YOU & QUESTIONS?

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let's create tomorrow, together

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