Signature Analysis of Cavitation in Centrifugal Pumps

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Motivation/Highlights

- Timely detection of cavitation in pumps is important as it can cause pitting, erosion, and loss of pump performance.
- Attempts to determine a unique signature of cavitation using vibration, acoustic emission, audible-acoustics, and higher order non-linear modeling techniques have been elusive.
- This workshop presents an the results of an experimental study undertaken first to understand the structure of cavitation and develop an effective means for on-line detection of it.

Workshop Agenda

This workshop will presents:

- Introduction to Cavitation
- Background Theory and Causes
- Current Detection Overview
- Video of Cavitation Development
- Experimental Details
- Results and Discussion
- Hands-on Demonstration
- Data Acquisition and Analysis
- Discussion

What is Cavitation

- A condition of formation to growth to collapse of small bubbles and to the occurrence of large amount of vapor
- **Cavitation** is the formation and then immediate implosion of cavities in a liquid – i.e. small liquid-free zones ("bubbles") – that are the consequence of forces acting upon the liquid.
- It usually occurs when a liquid is subjected to rapid changes of pressure that cause the formation of cavities where the pressure is relatively low.
- Occurs when Net Positive Suction Head (NPSH) drops below the saturation vapor pressure

Serious Consequences of Cavitation

- Loss of performance
- Vapor locking
- Damage to Equipment
- Loss of life

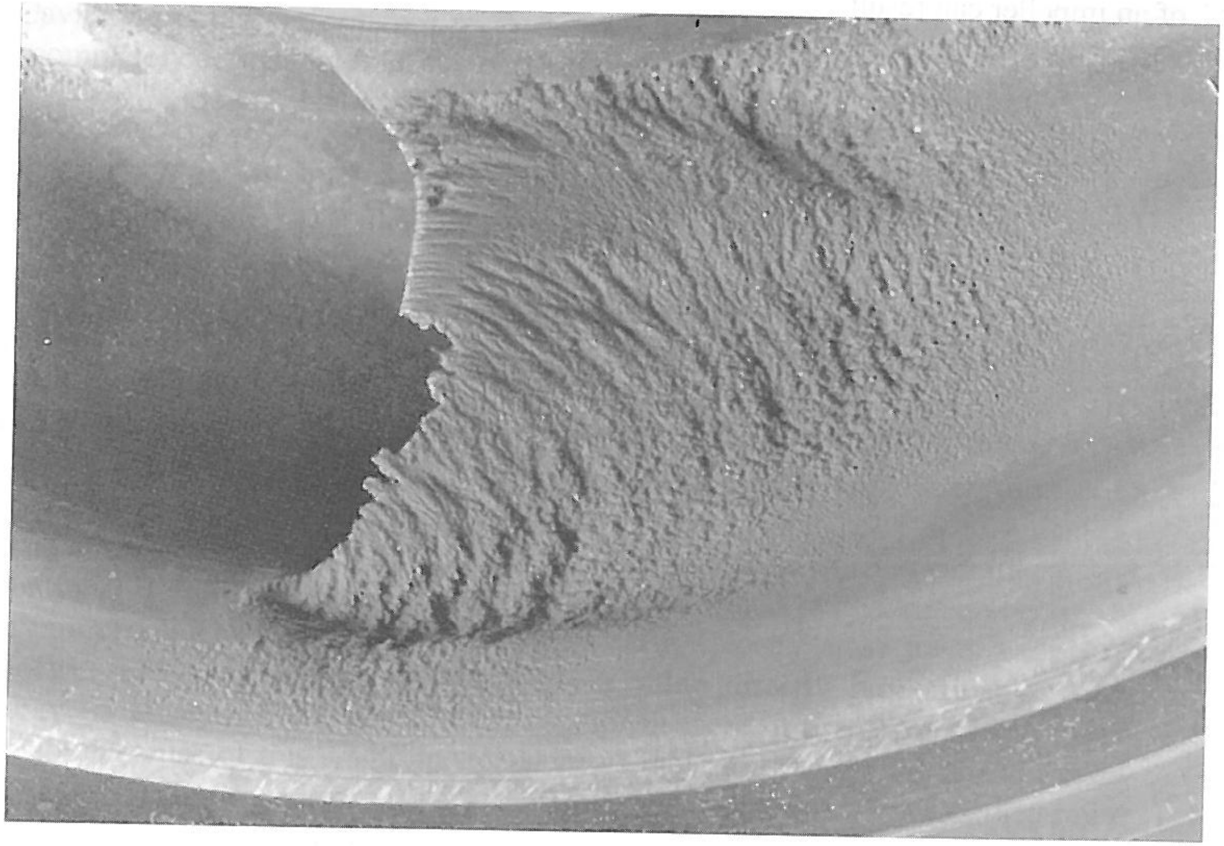


Fig. 1.7 Typical cavitation erosion damage on an impeller blade
Courtesy of Sulzer Pumps Ltd.

Courtesy of Cavitation and the
Centrifugal Pump by Edward Grist

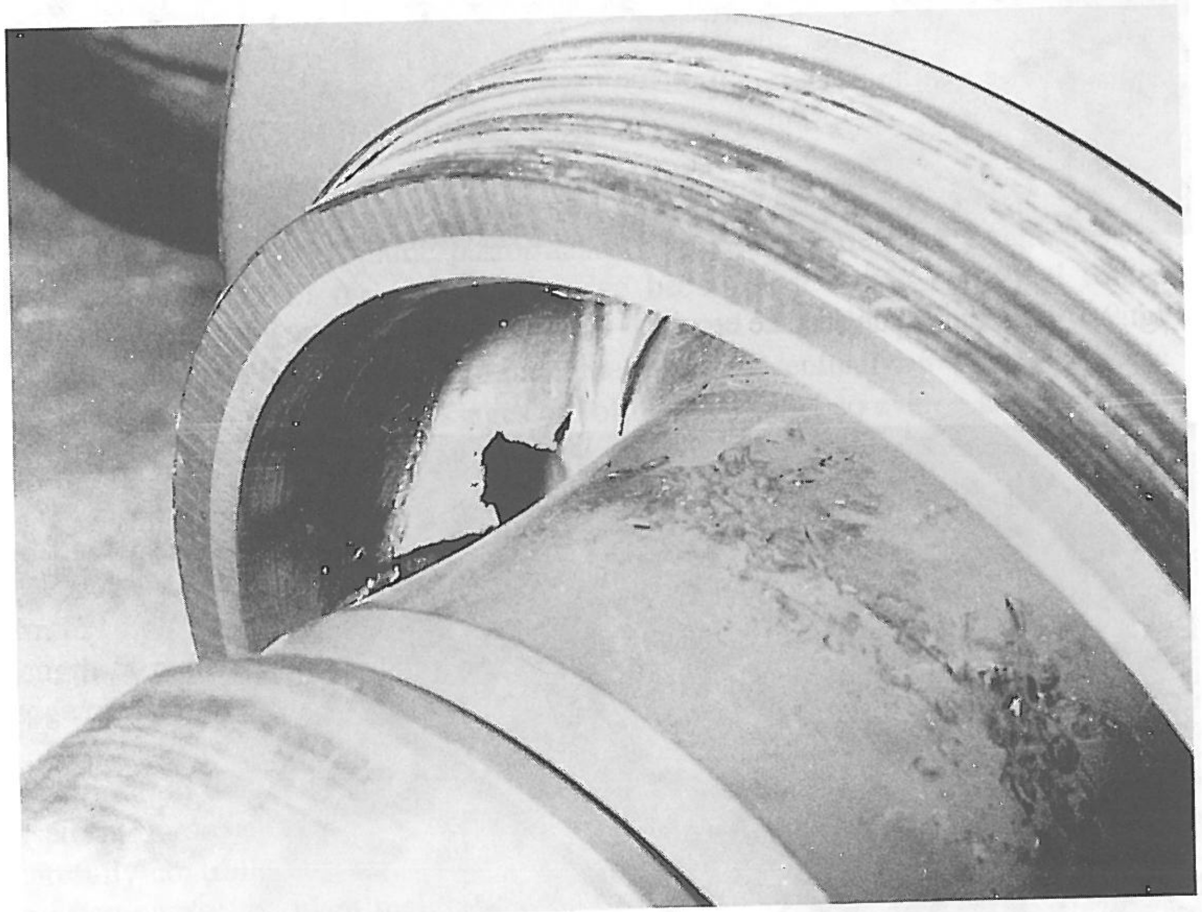


Fig. 9.3 Impeller blade edge failure

Courtesy of Cavitation and the Centrifugal Pump by Edward Grist

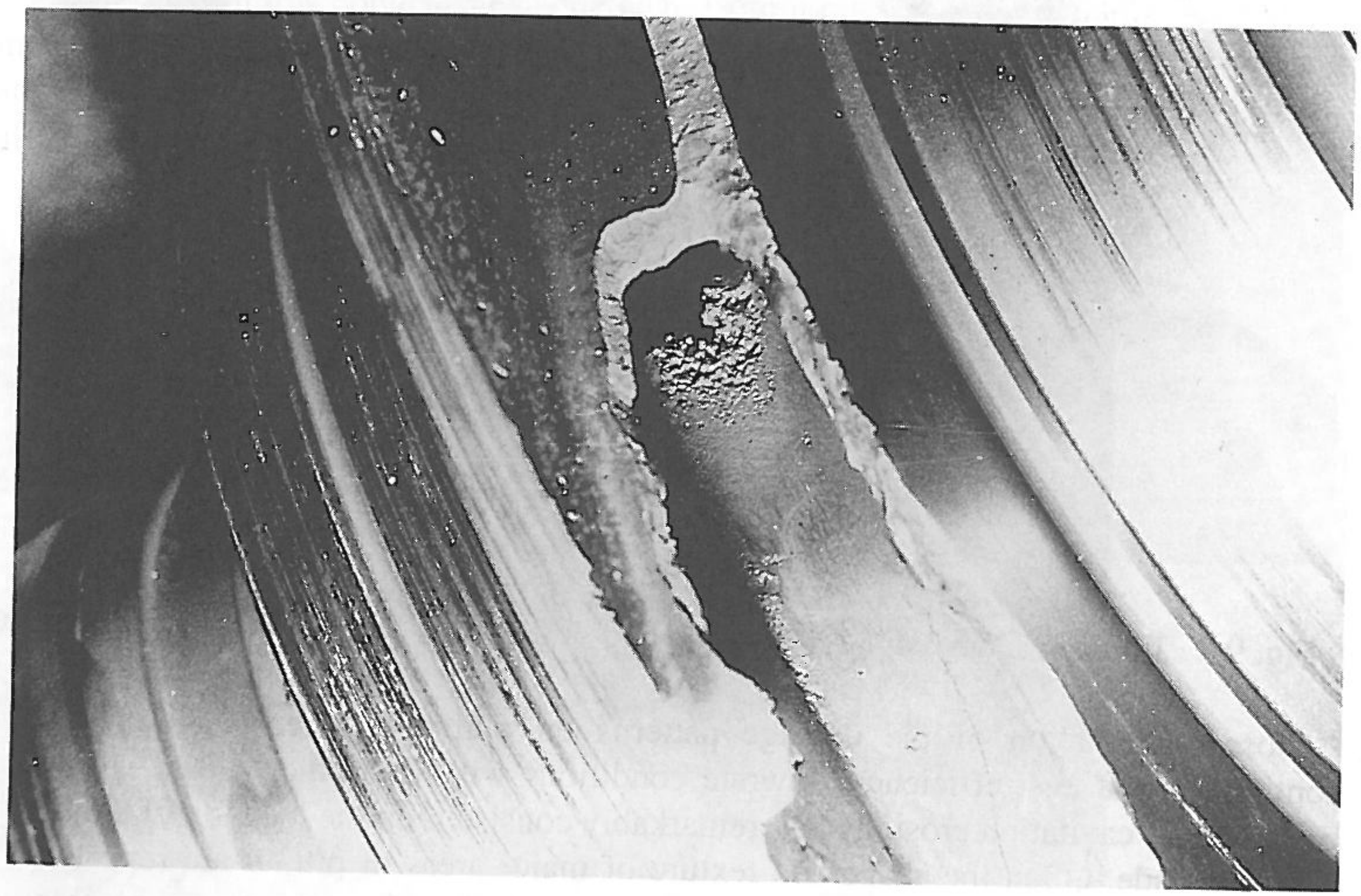
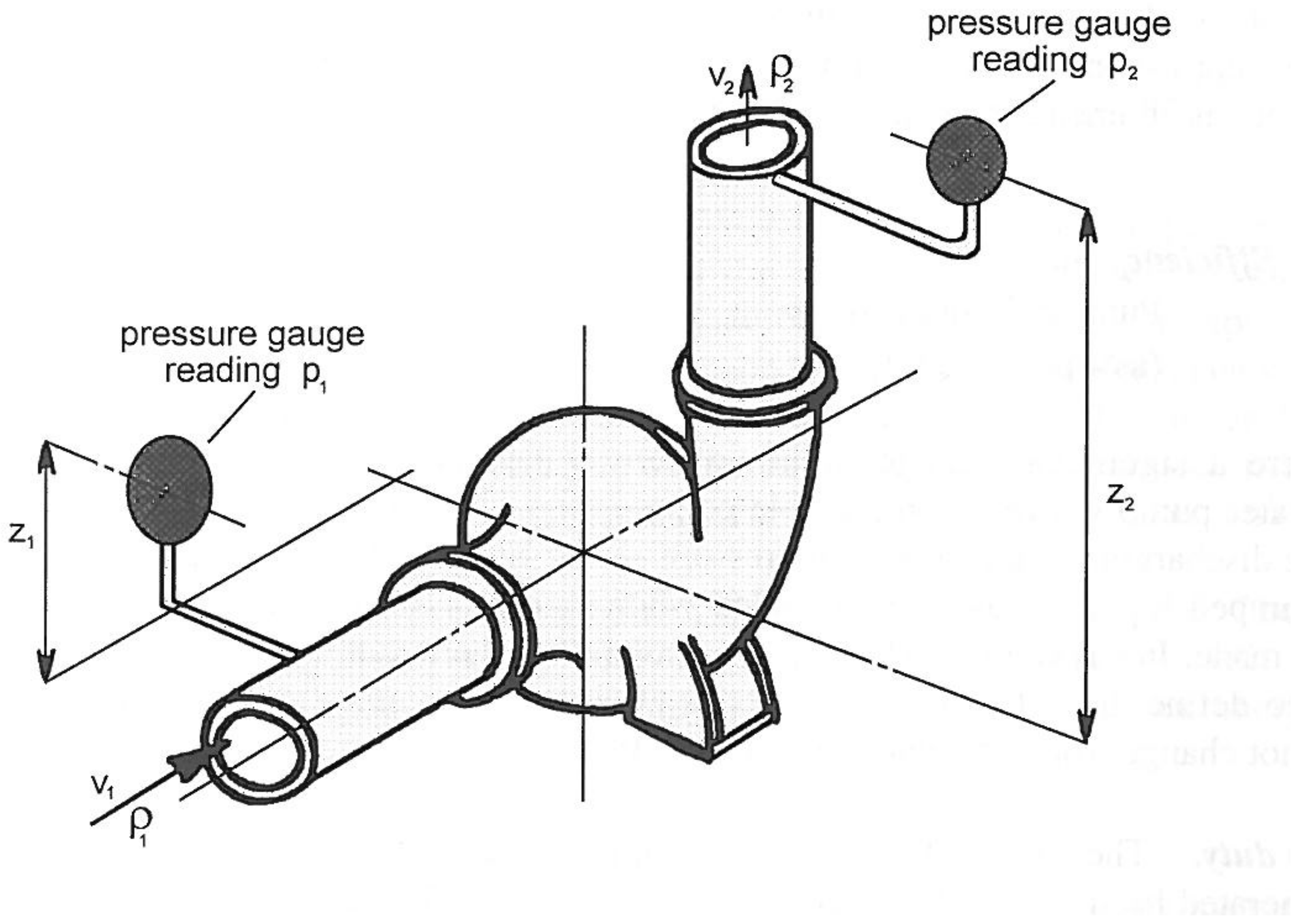


Fig. 9.5 Impeller outlet edge damage following inlet edge failure

Courtesy of Cavitation and the Centrifugal Pump by Edward Grist

Pictorial View of Terminology



Courtesy of Cavitation and the
Centrifugal Pump by Edward Grist

Performance Terminology & Definitions

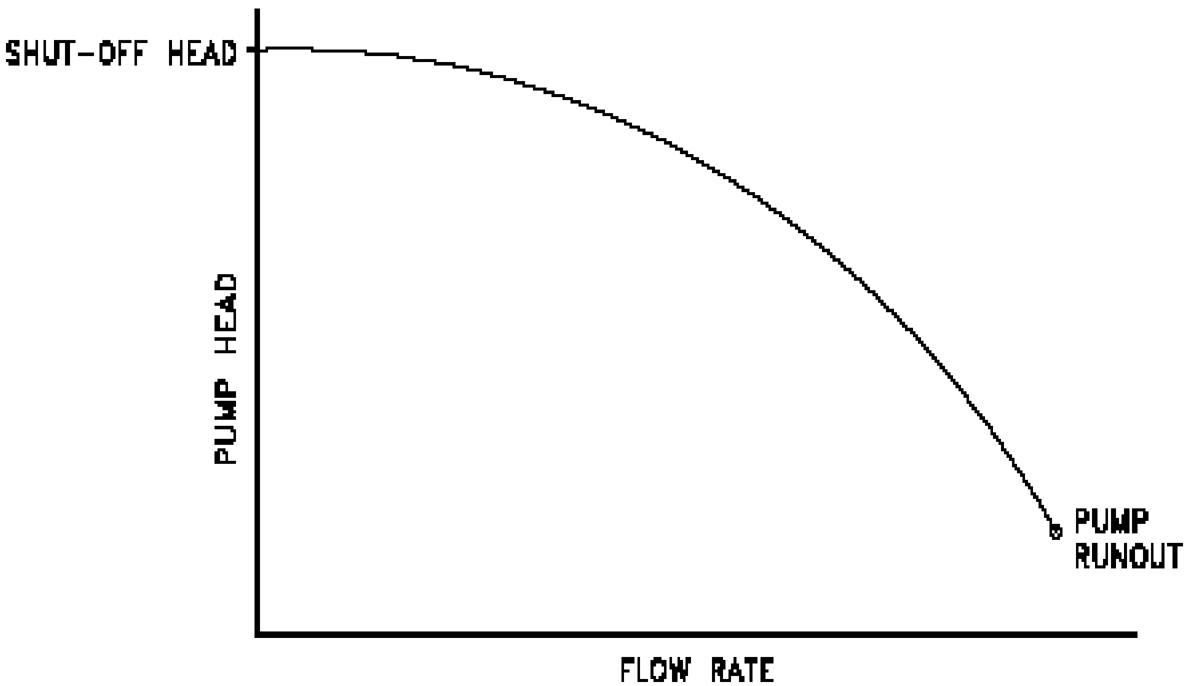
Inlet total head $$H_1 = z_1 + \frac{p_1}{\rho_1 g} + \frac{v_1^2}{2g}$$

Outlet total head $$H_2 = z_2 + \frac{p_2}{\rho_2 g} + \frac{v_2^2}{2g}$$

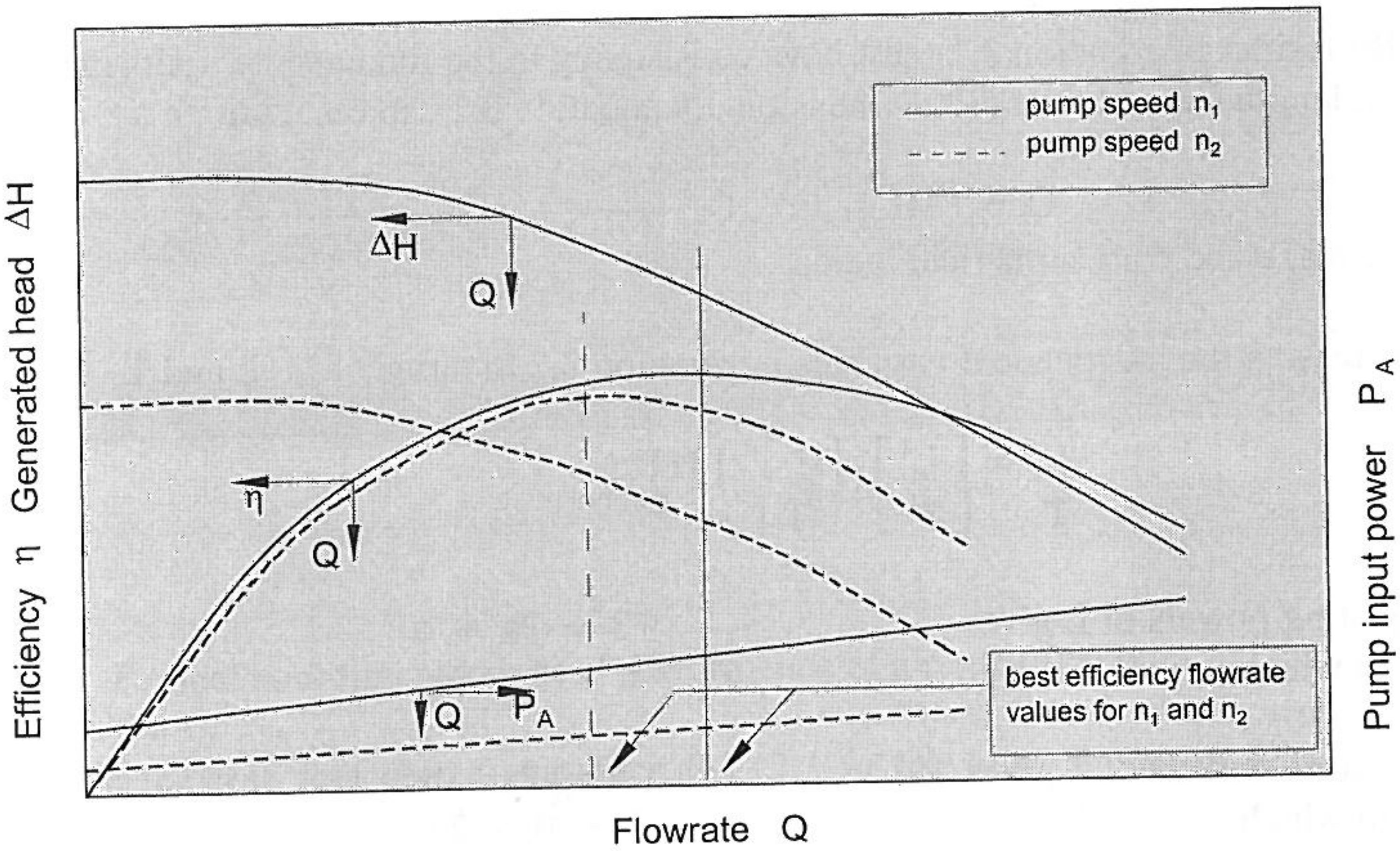
Generated head **ΔH.**

$$\Delta H = H_2 - H_1$$

Pump Performance Curve



Pump Performance Curve



Courtesy of Cavitation and the Centrifugal Pump by Edward Grist

Net Positive Suction Head "NPSH"

To avoid cavitation in centrifugal pumps, the pressure of the fluid at all points within the pump must remain above saturation pressure.

The **net positive suction head** available (NPSHA) is the difference between the pressure at the suction of the pump and the saturation pressure for the liquid being pumped.

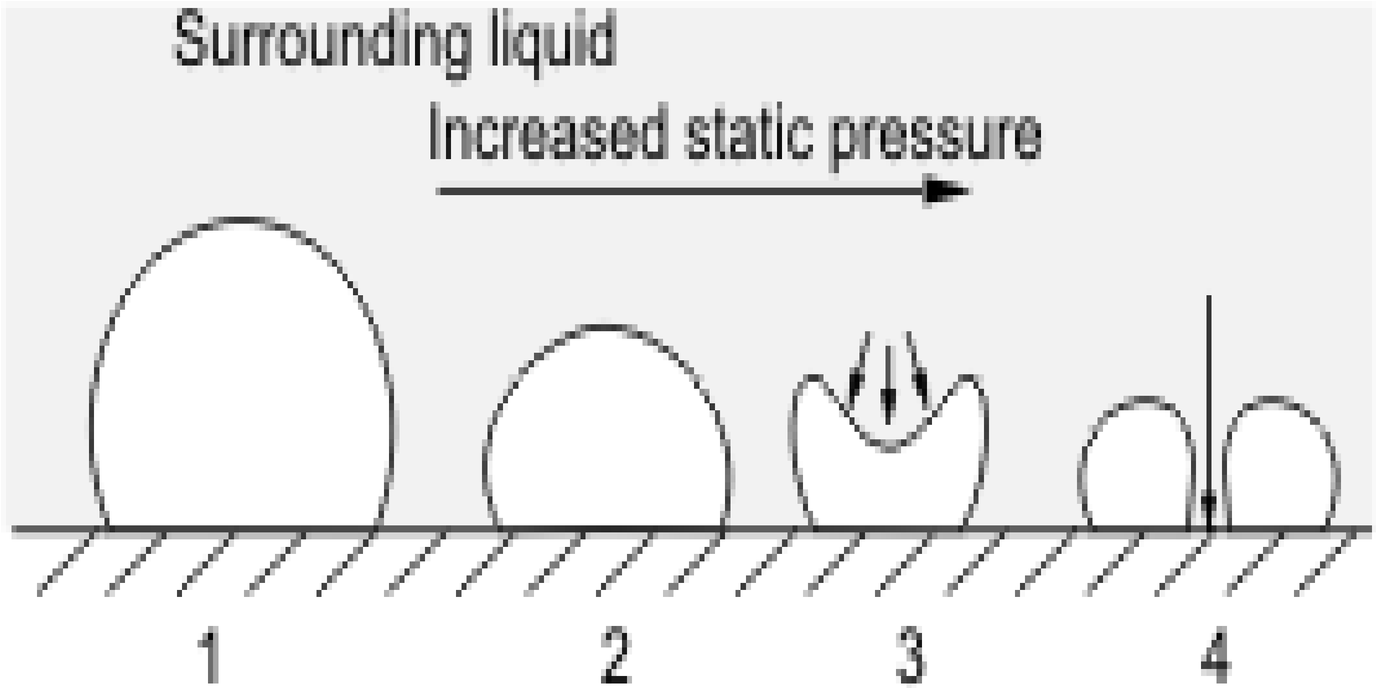
$$NPSH = H_1 + \frac{p_b}{\rho_L g} - \frac{p_{vap}}{\rho_L g}$$

The condition that must exist to avoid cavitation

The *net positive suction head required* (NPSHR) is the minimum net positive suction head necessary to avoid cavitation.

$$NPSH_A \geq NPSH_R$$

Bubble Implosion Steps



Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.

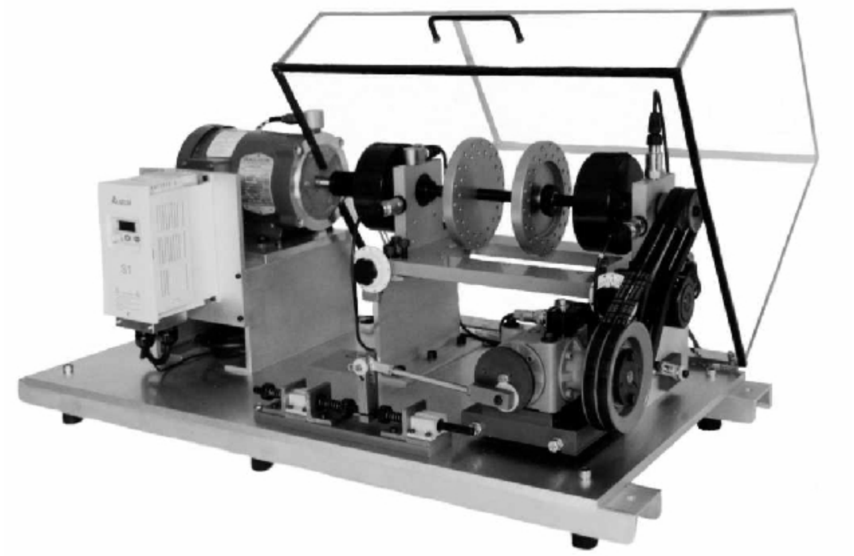
Experiment Setup

Tests were performed using SpectraQuest Machinery Fault Simulator on direct coupled and belt driven pumps.

The following parameters were measured:

- Vibration
- Pressure
- Sound
- Motor current
- And the force due to cavitation of a centrifugal pump.

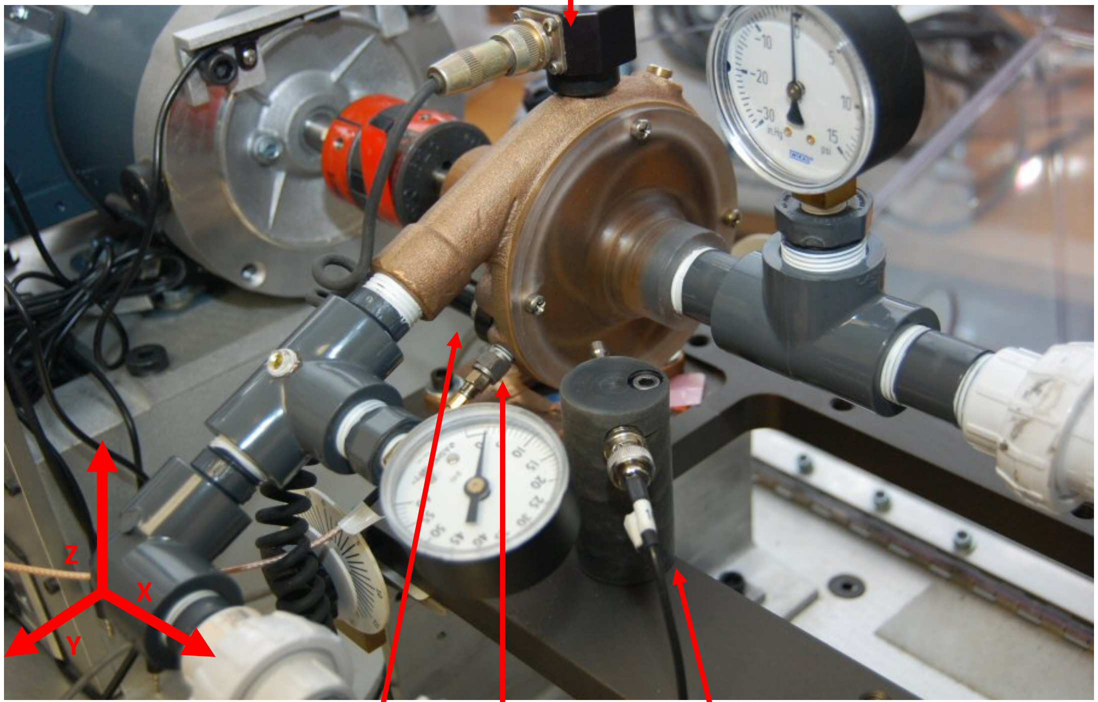
Experiment Setup



Machinery Fault Simulator with Pump Kit

Experiment Setup - Sensors

Tri-axial accelerometer



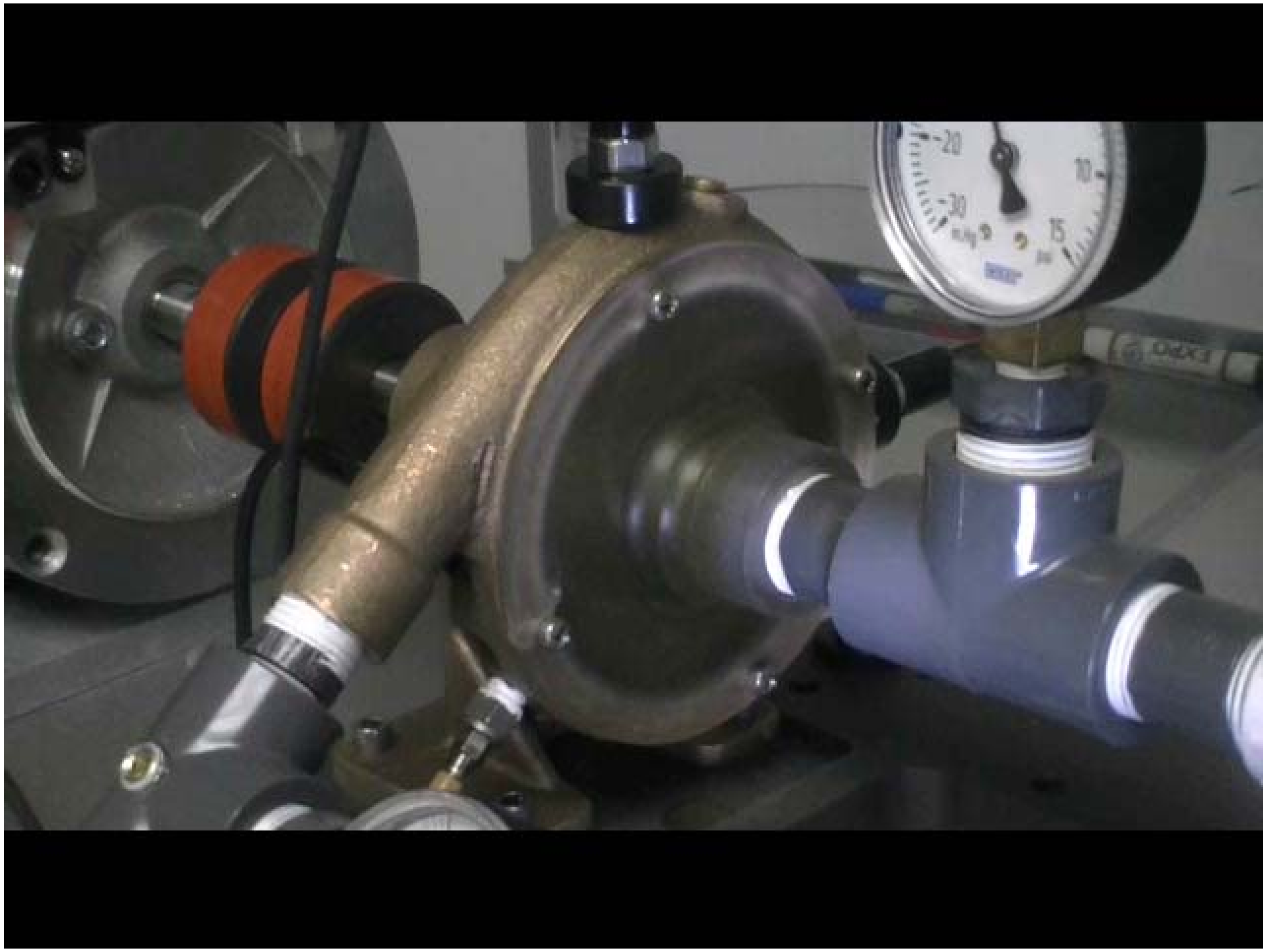
Accelerometer

(Axial Dir)

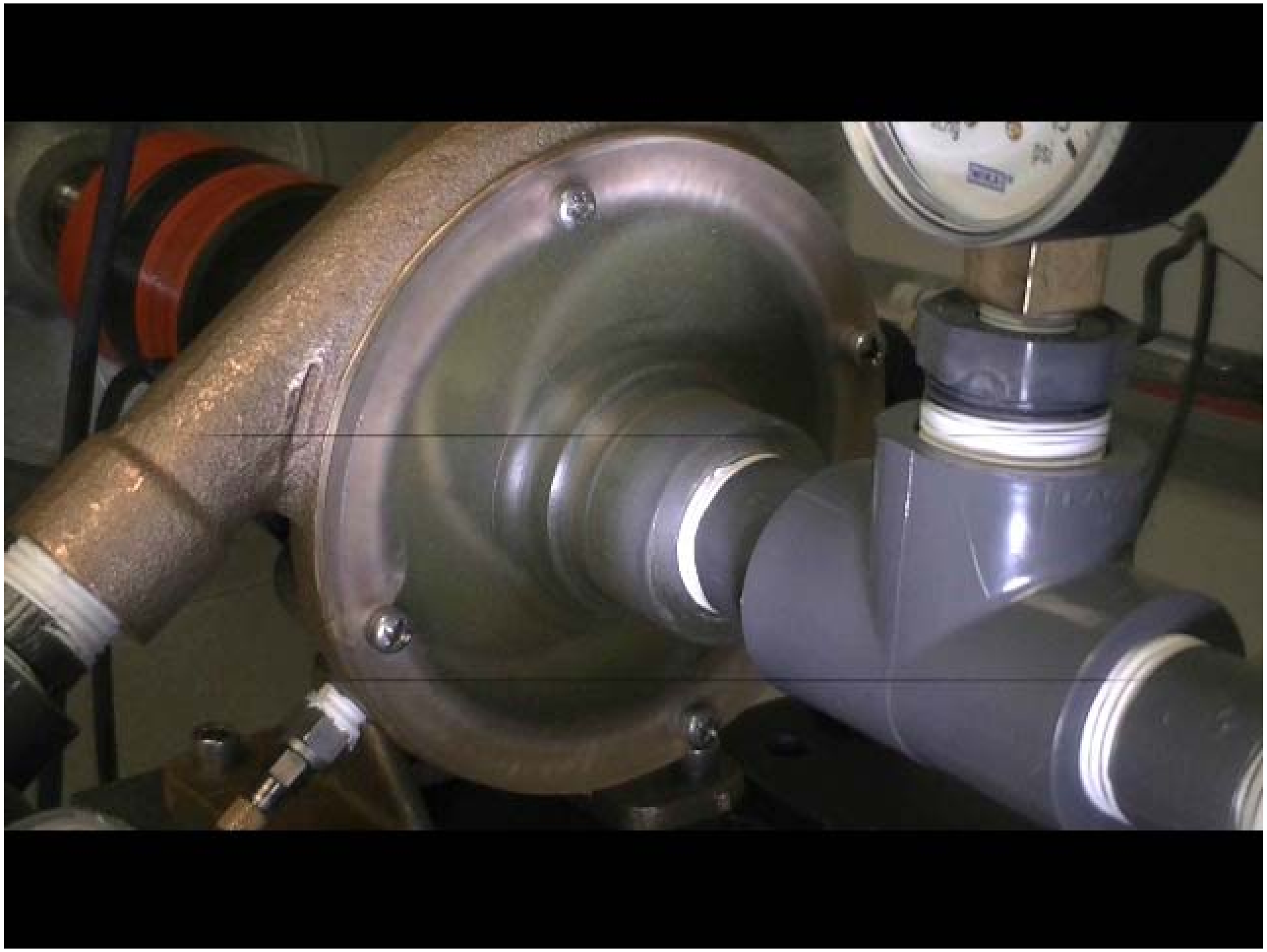
Pressure Sensor

Microphone

No Cavitation



Development of Cavitation



Severe cavitation-Plain water

Severe Cavitation – Colored Water

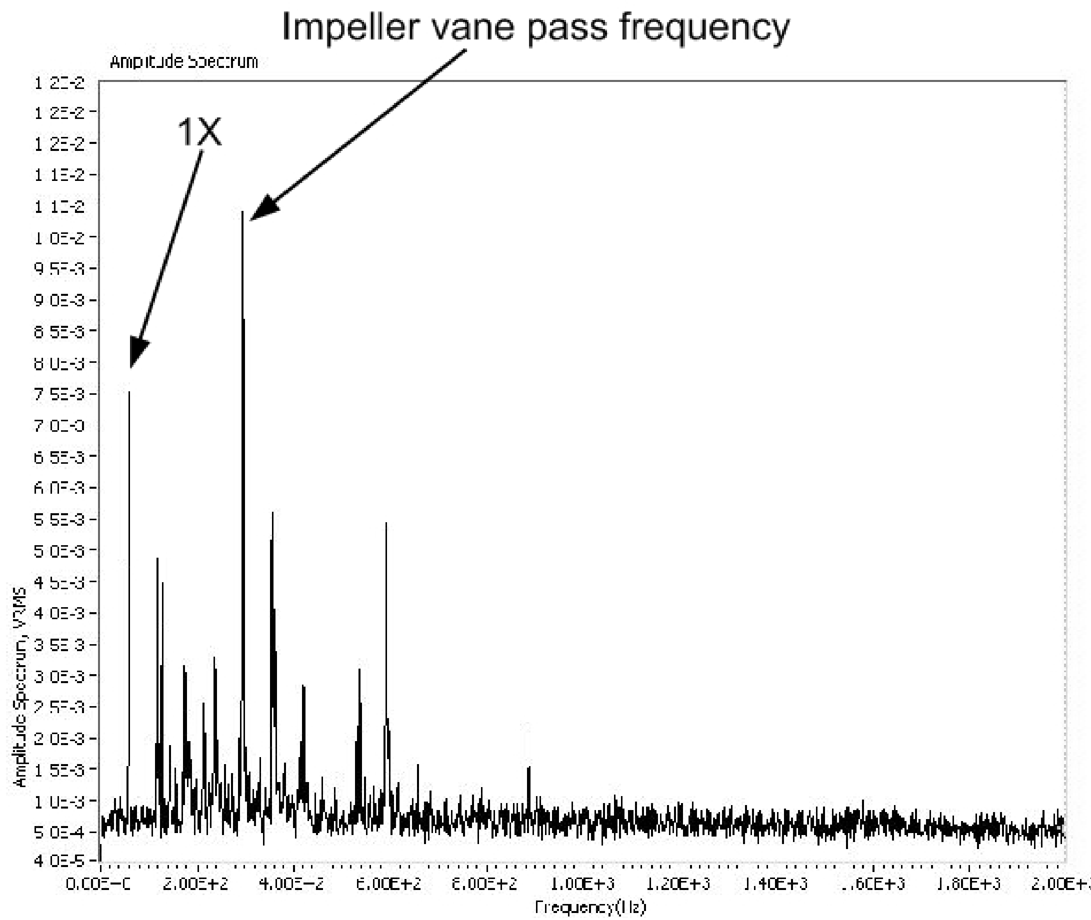
Test Conditions

1) The valve is full open
2) The valve is closed somewhat until the appearance of cavitation
3) The valve is closed continuously until severe cavitation is observed.

The pressures are shown in Table 1.

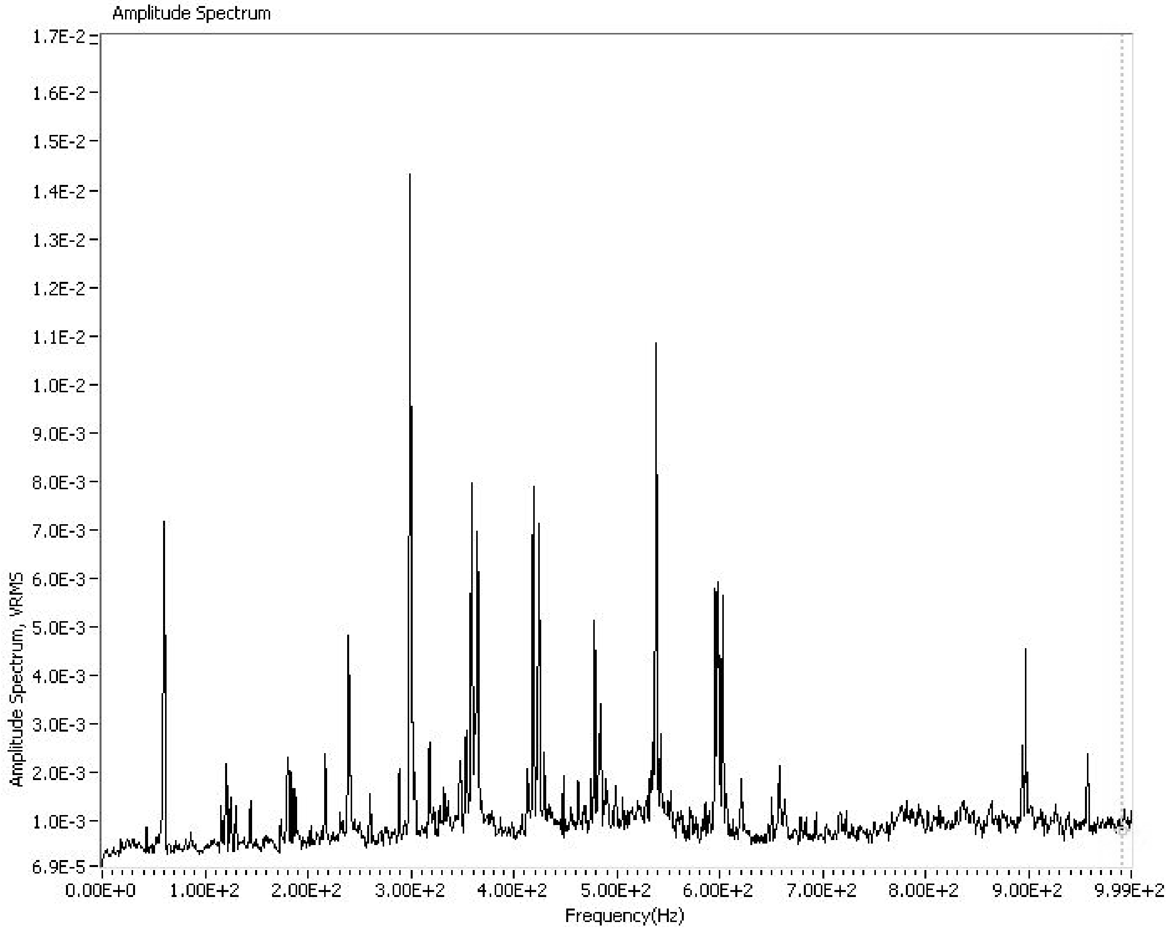
Pump RPM	Valve position	Pump Head Pressure (inHg)	Pump Discharge Pressure (psi)
3600	Full open	-5	14~15 (depends on air bubble)
	Cavitation appear	-13	13
	Severe cavitation	-20	9
3000	Full open	-4	11
	Cavitation appear	-20	5.5
	Severe cavitaiton	-21	3.5
2400	Full open	-2.5	8
	Cavitation appear	-18	3
	Further valve closing will cut water off		
1800	Full open	-1.5	5
	No cavitation can be generated		

Typical Data



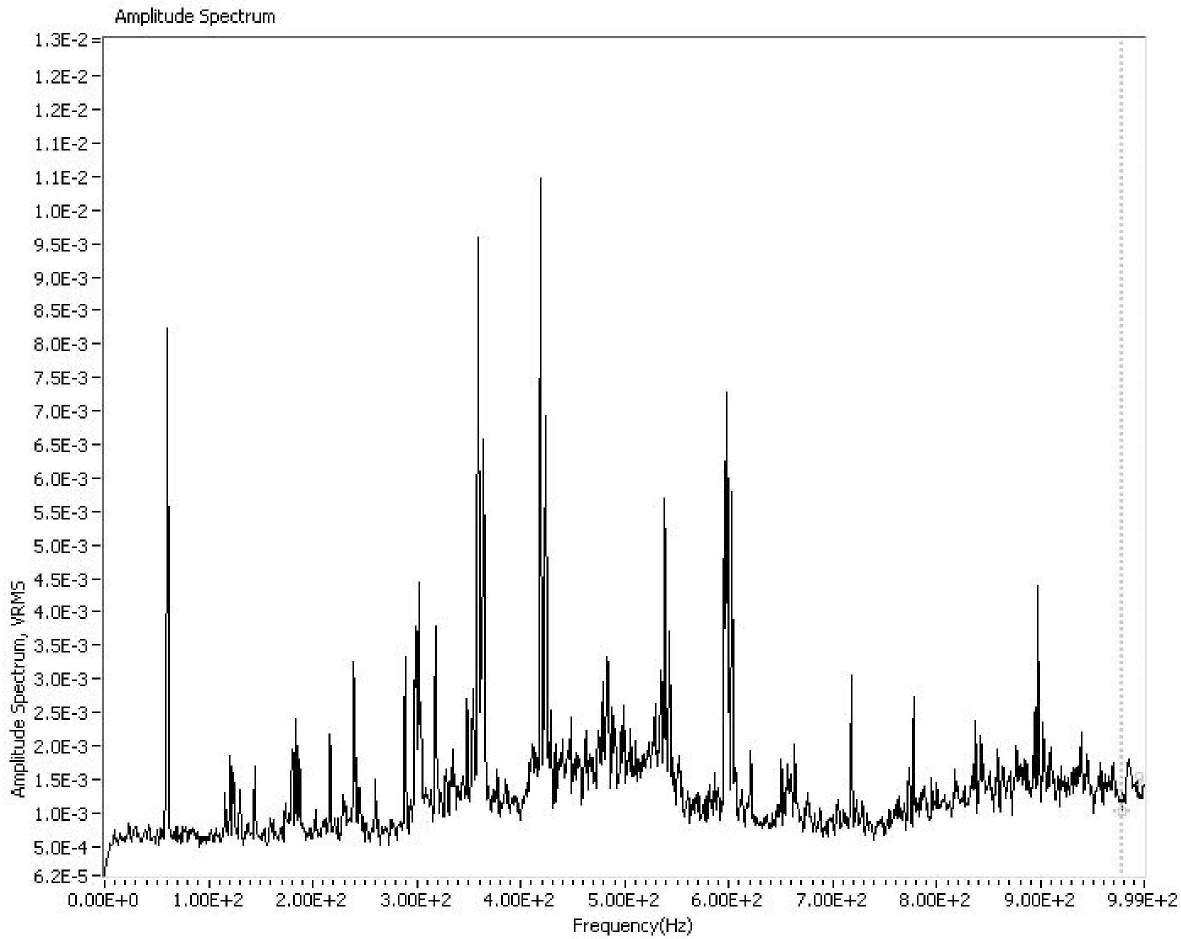
Pump Vibration with Tank Discharge Valve Full Open
(3619 RPM) Radial Vibration (2 KHz)

Typical Data



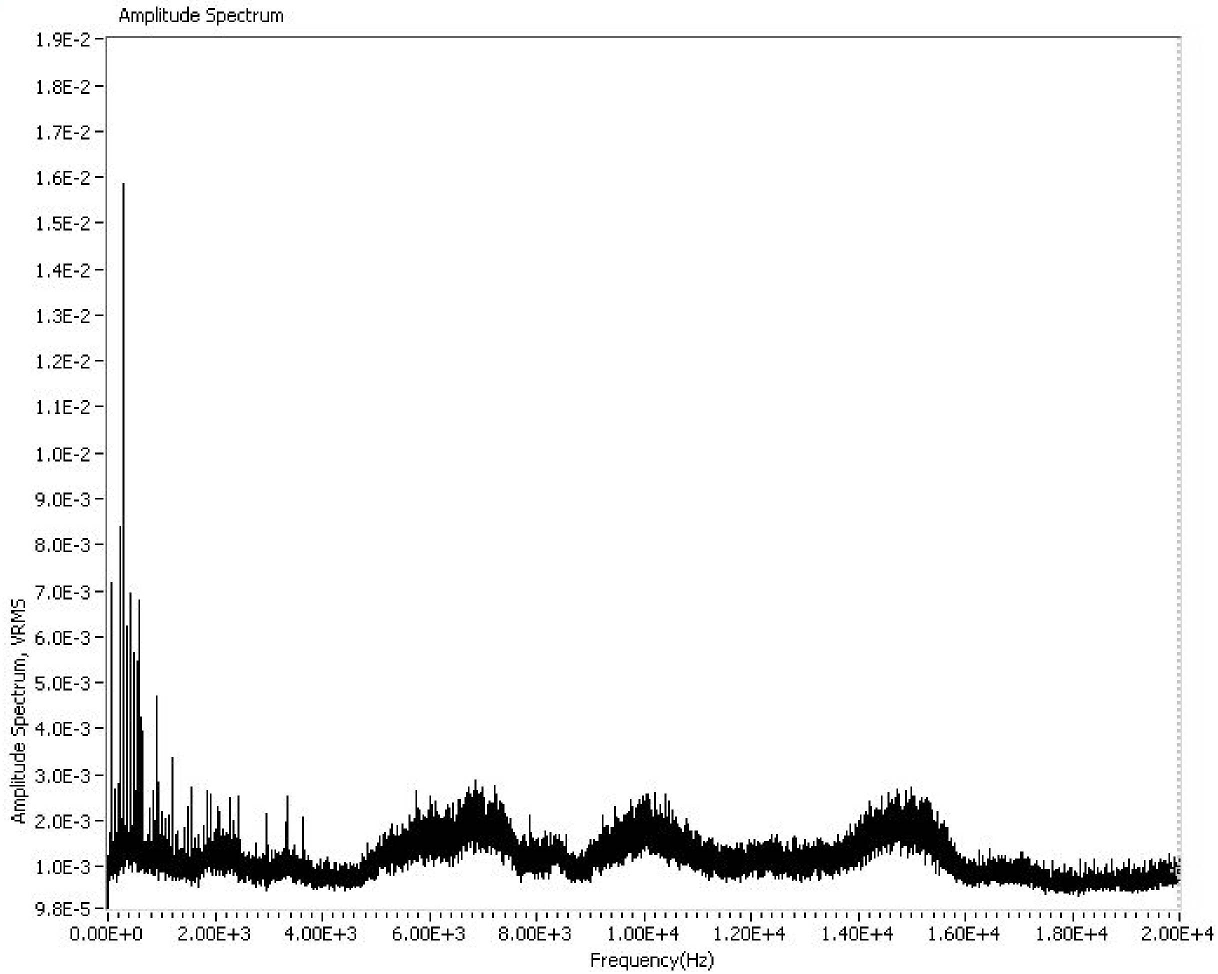
Radial Vibration (1 KHz)
Pump Vibration with Appearance of Cavitation (3616 RPM)

Typical Data



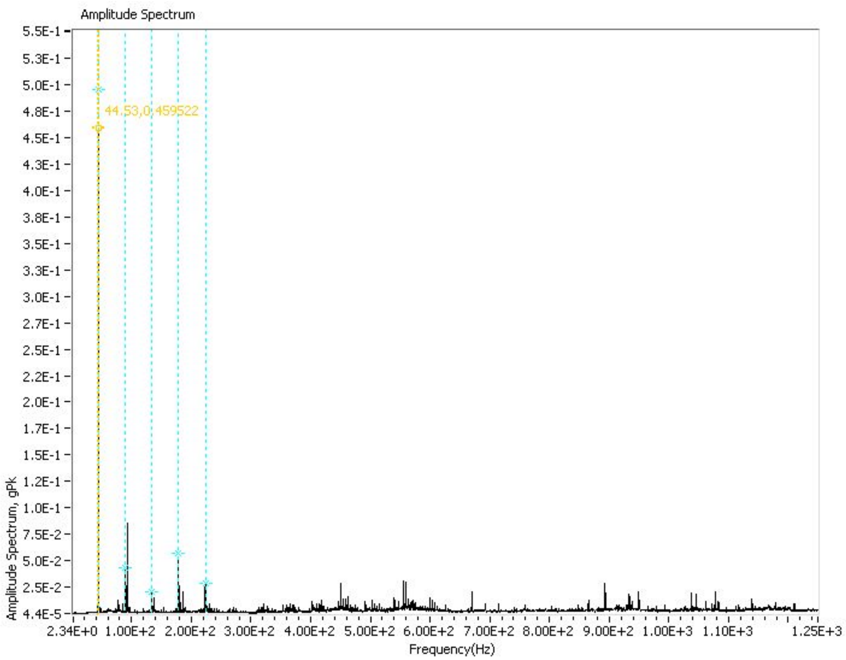
Radial Vibration (1 KHz)
Pump Vibration with Severe Cavitation (3617 RPM)

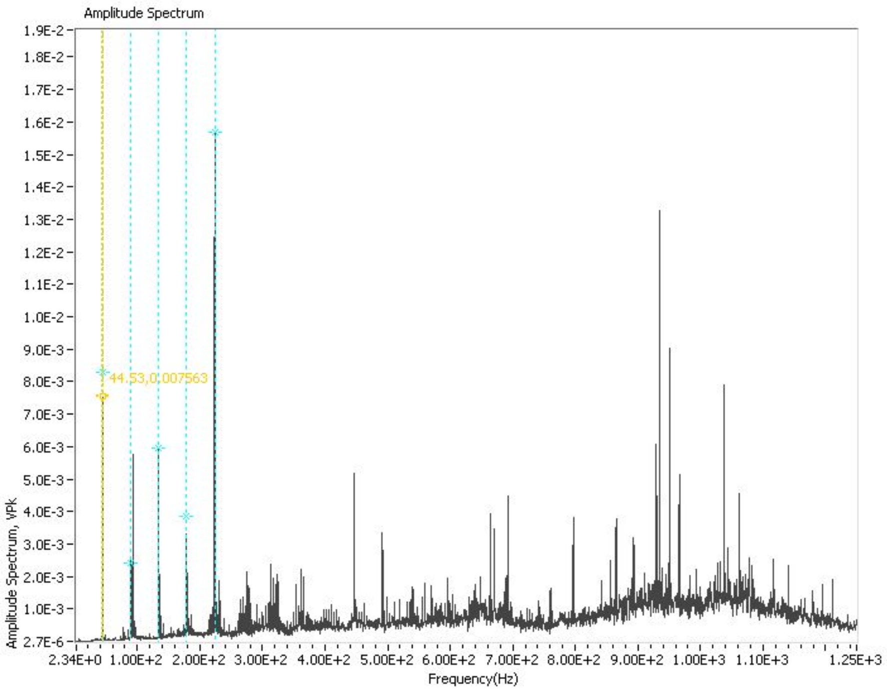
Typical Data



Radial Vibration (20 KHz)

Typical Data – Vibration Comparison Axial

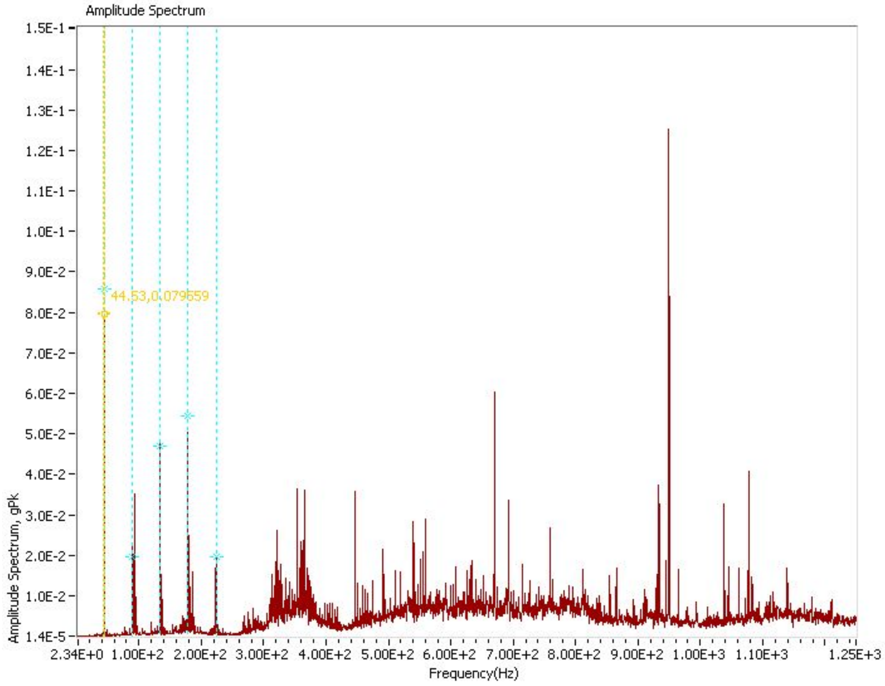


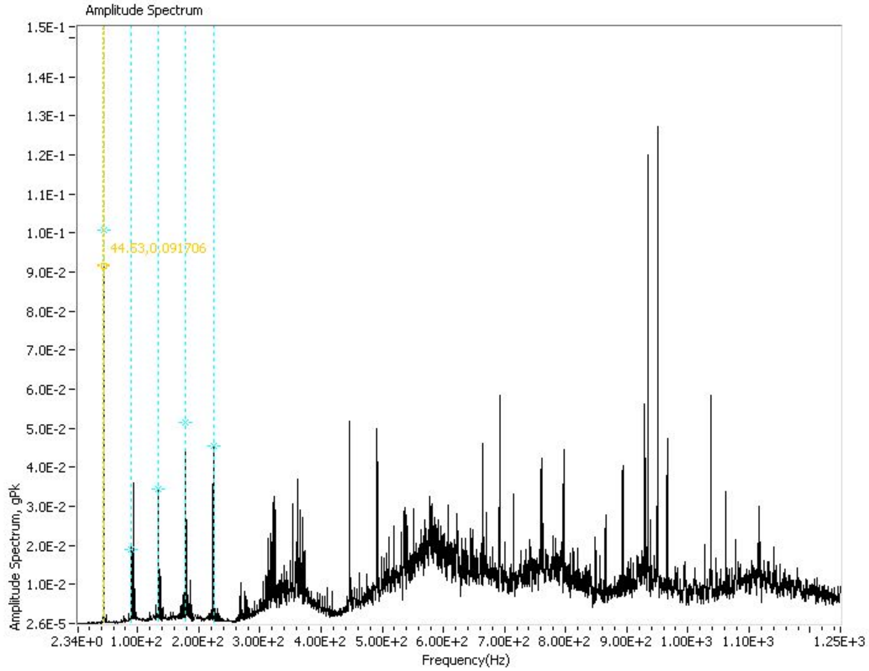


45 Hz Baseline Vibration Axial

45 Hz fully developed cavitation Vibration Axial

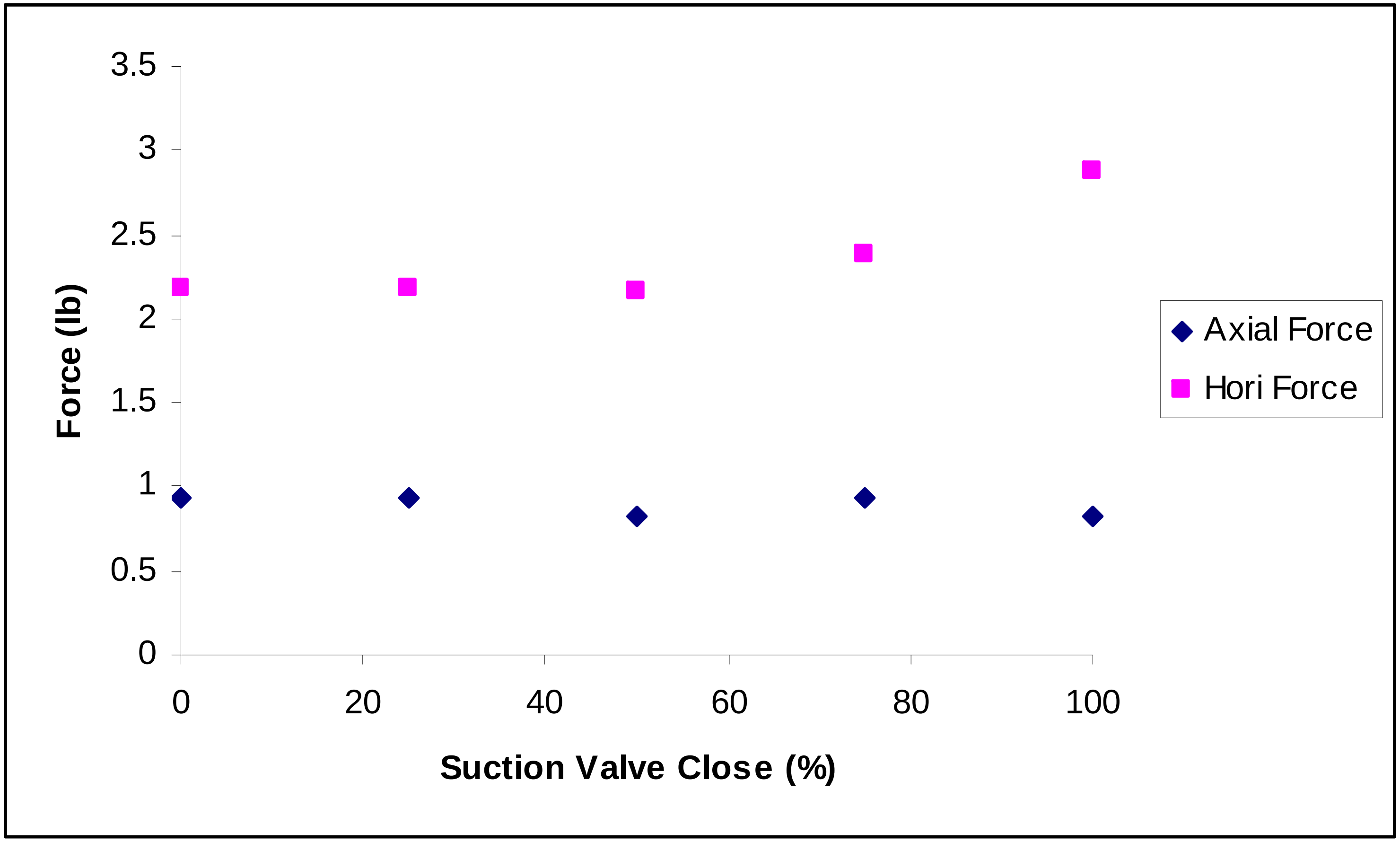
Typical Data – Vibration Comparison Vertical





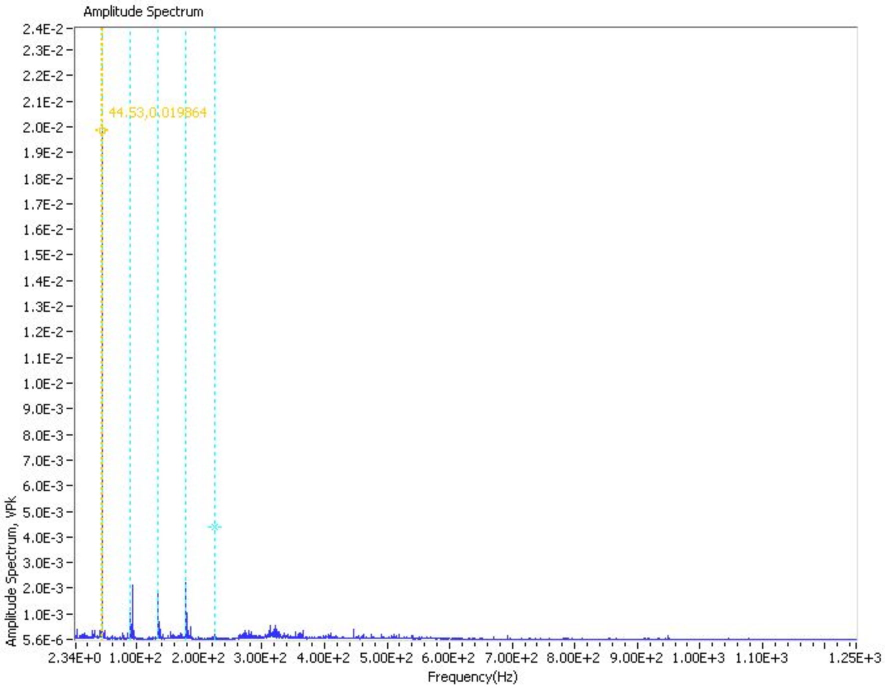
45 Hz Baseline Vibration Vertical

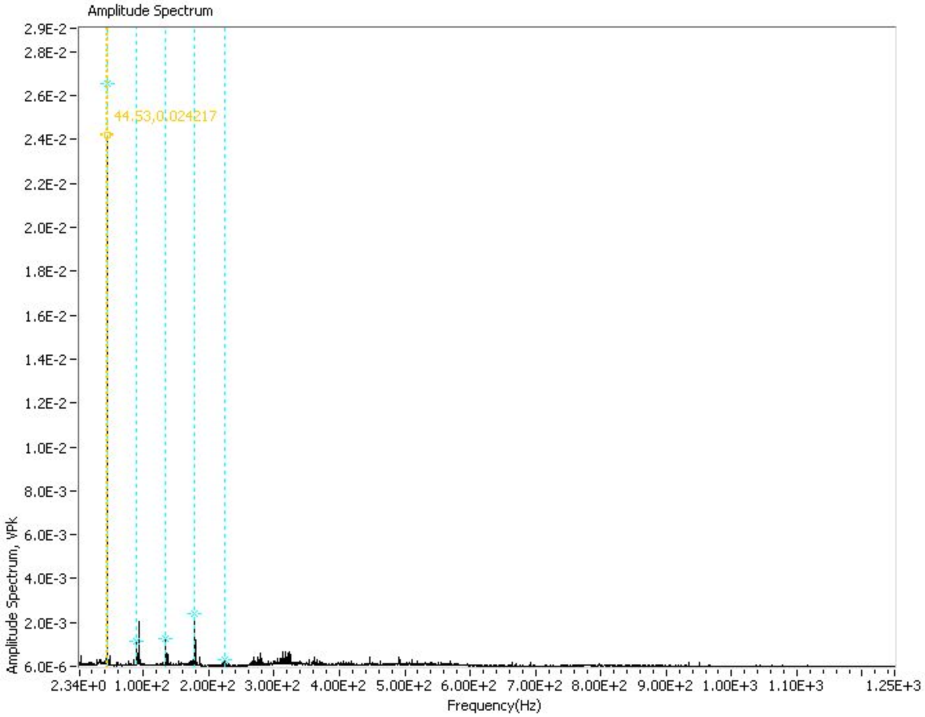
45 Hz fully developed cavitation Vibration Vertical



Variation of Axial and Horizontal Force (60 Hz)

Typical Data – Force Comparison Axial

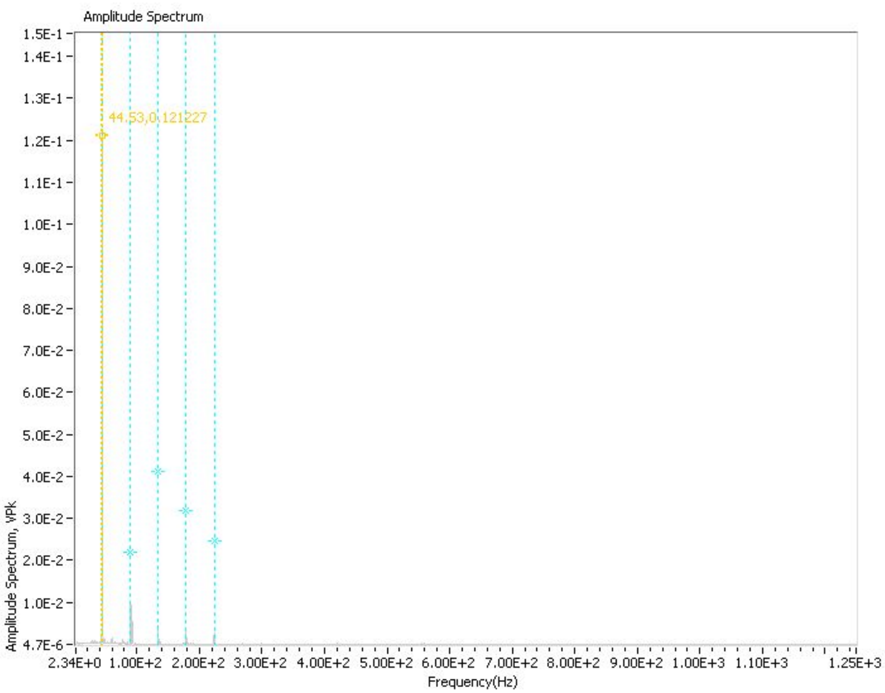


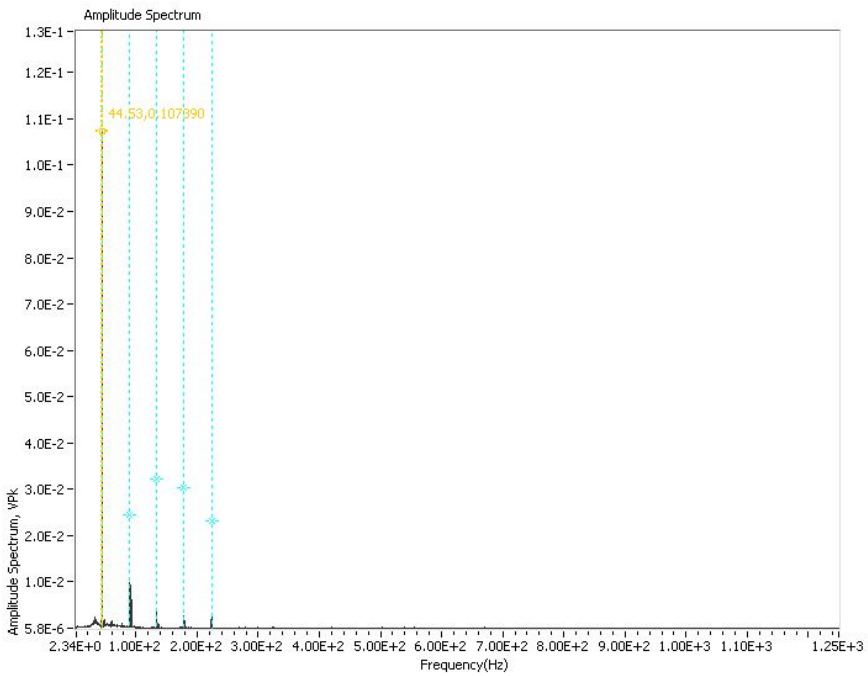


45 Hz Baseline Force Axial

45 Hz fully developed cavitation Force Axial

Typical Data – Force Comparison Horizontal

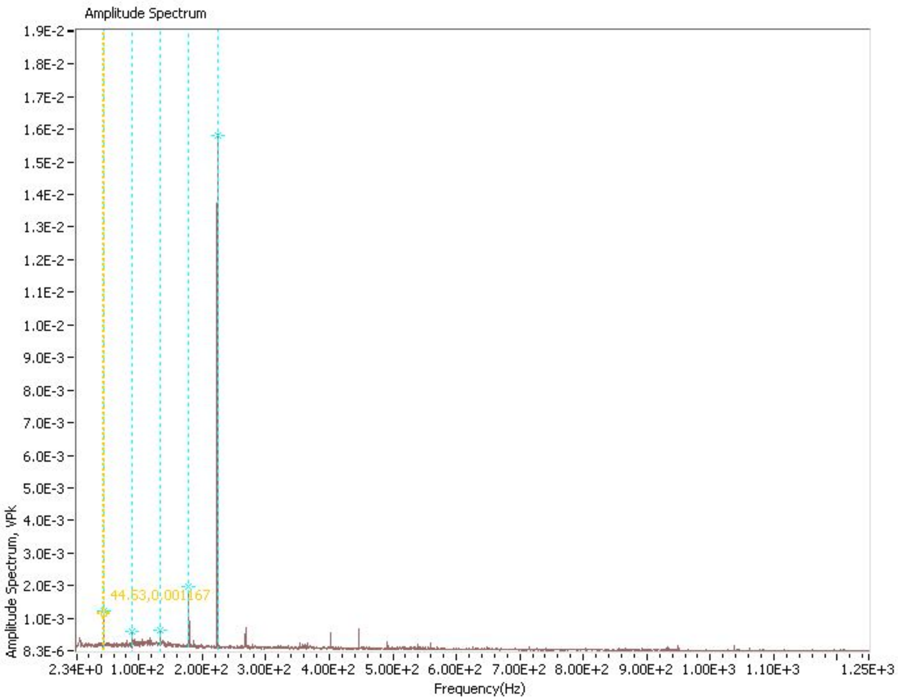




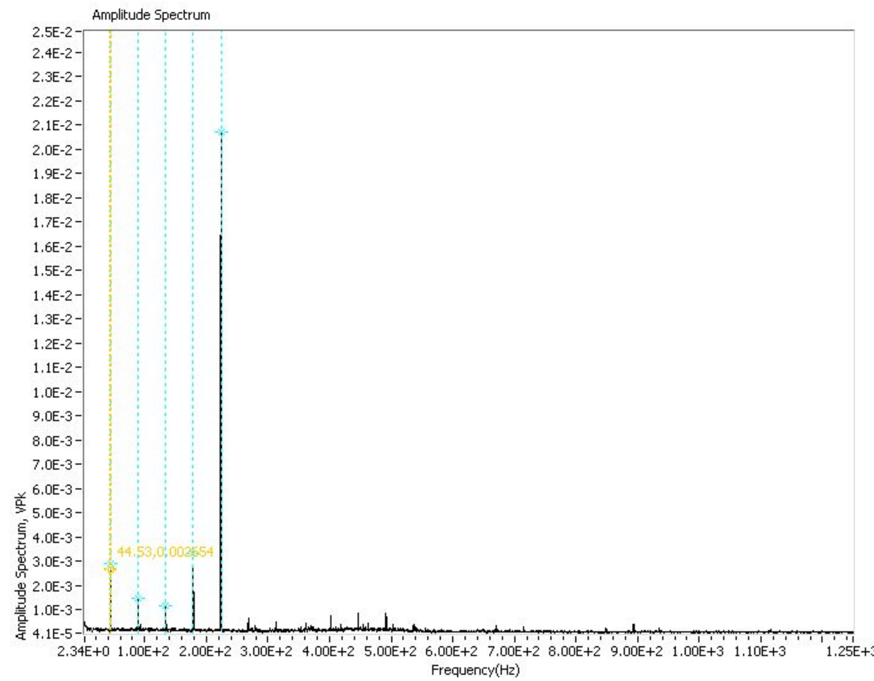
45 Hz Baseline Force Horizontal

45 Hz fully developed cavitation Force Horizontal

Typical Data – Pressure Comparison

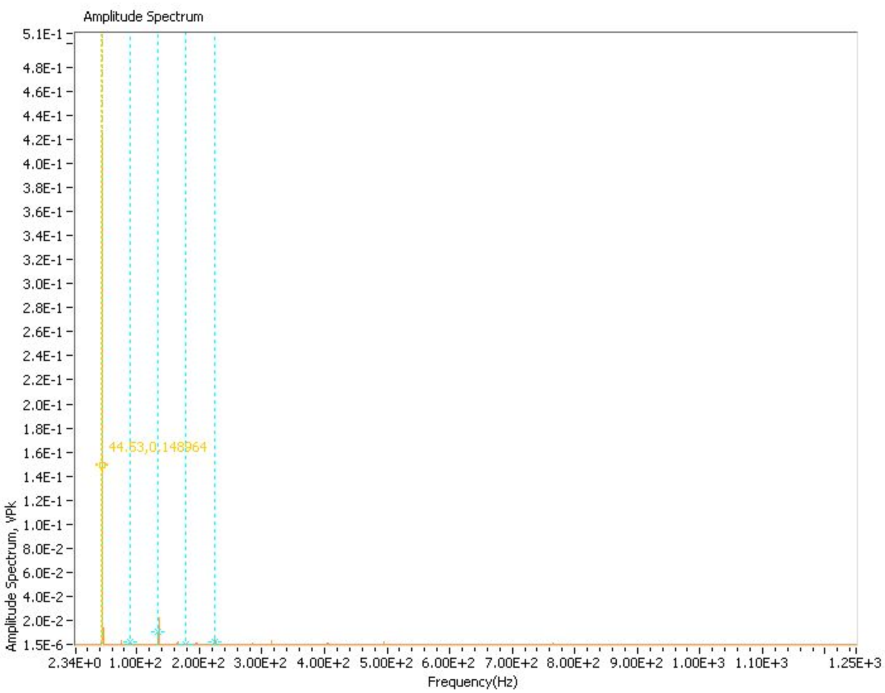


45 Hz Baseline Pressure

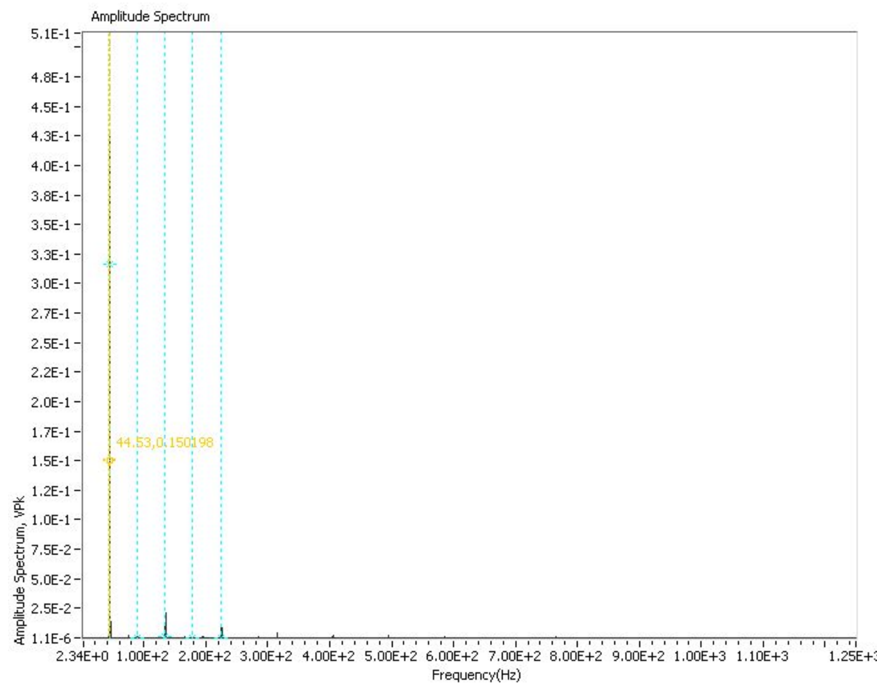


45 Hz fully developed cavitation Pressure

Typical Data – Motor Current Comparison

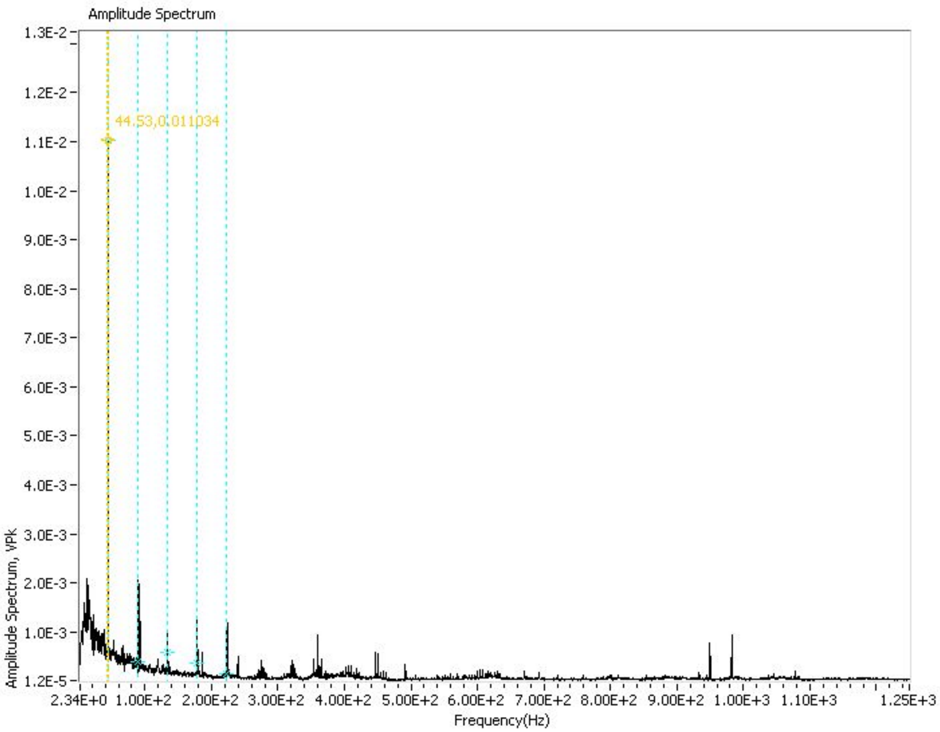


45 Hz Baseline Current

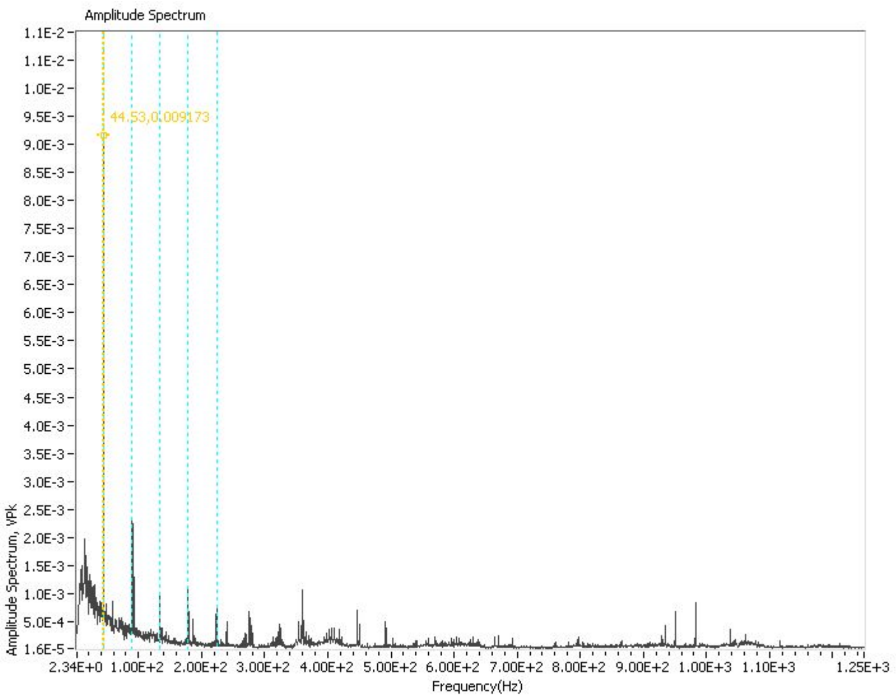


45 Hz fully developed cavitation Current

Typical Data – Noise Comparison

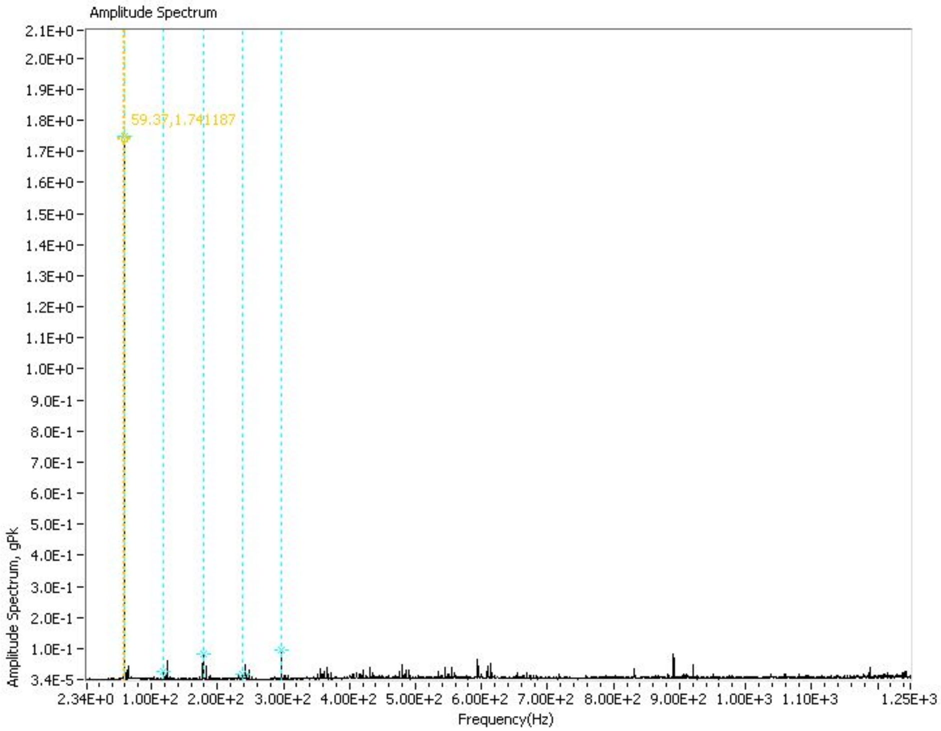


45 Hz Baseline Noise

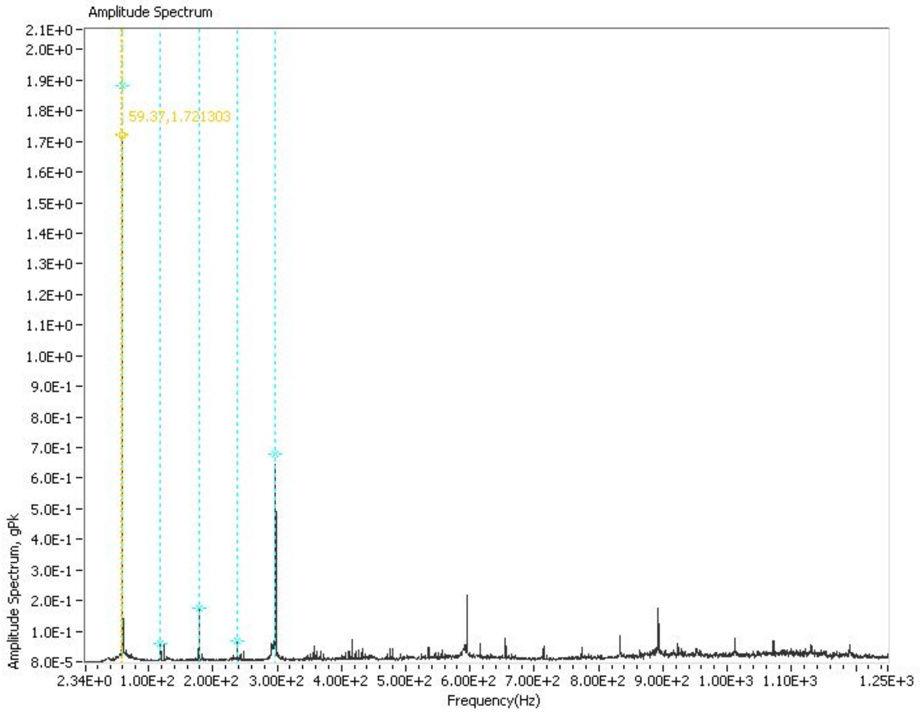


45 Hz fully developed cavitation Noise

Typical Data – Direct Drive 60Hz Vibration Comparison

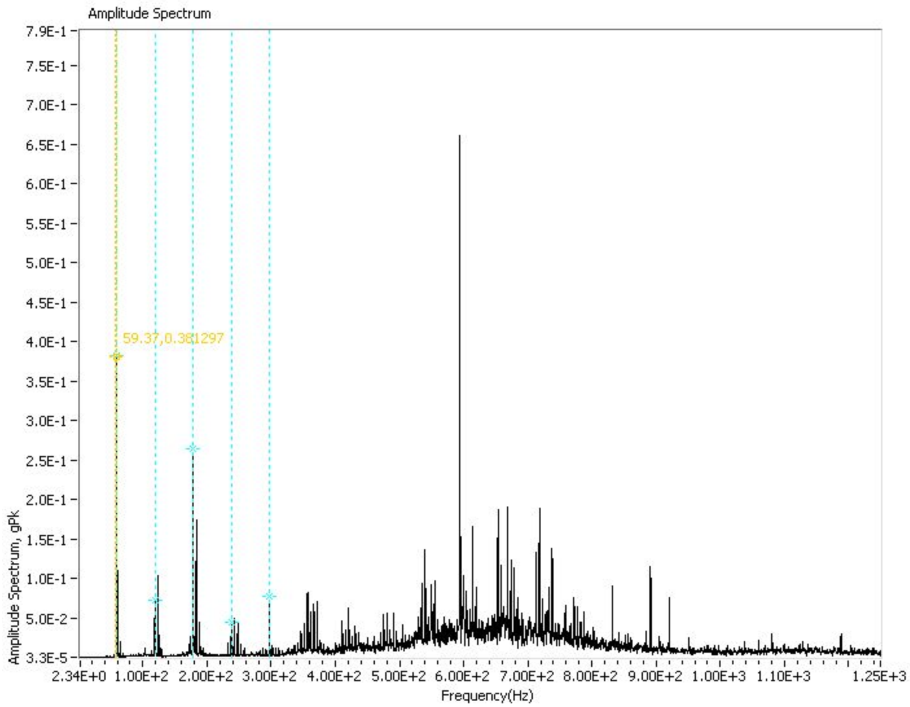


60 Hz Baseline Vibration Axial

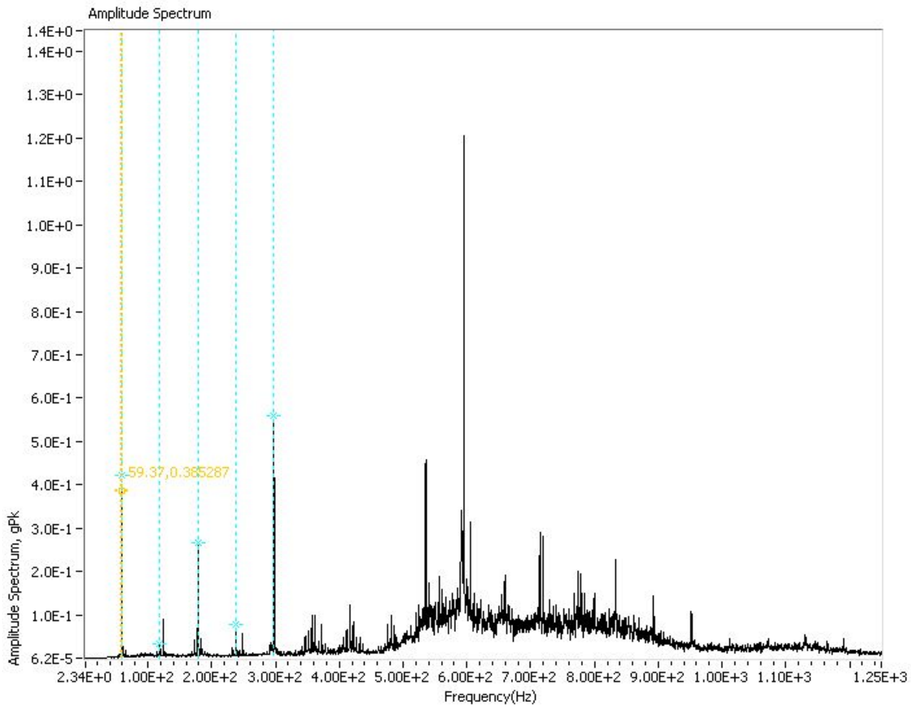


60 Hz fully developed cavitation Vibration Axial

Typical Data – Direct Drive 60Hz Vibration Comparison

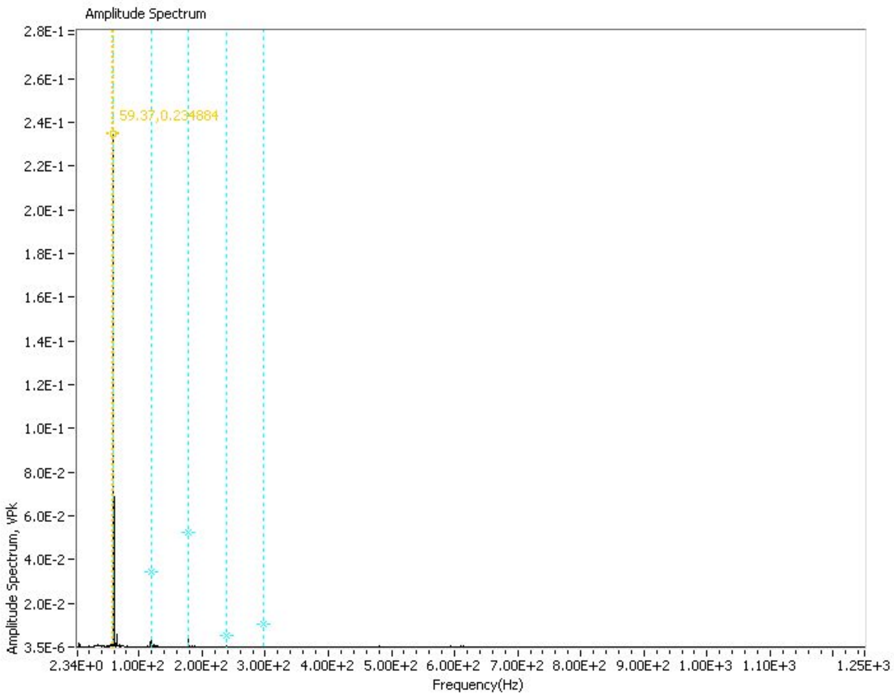


60 Hz Baseline Vibration Horizontal

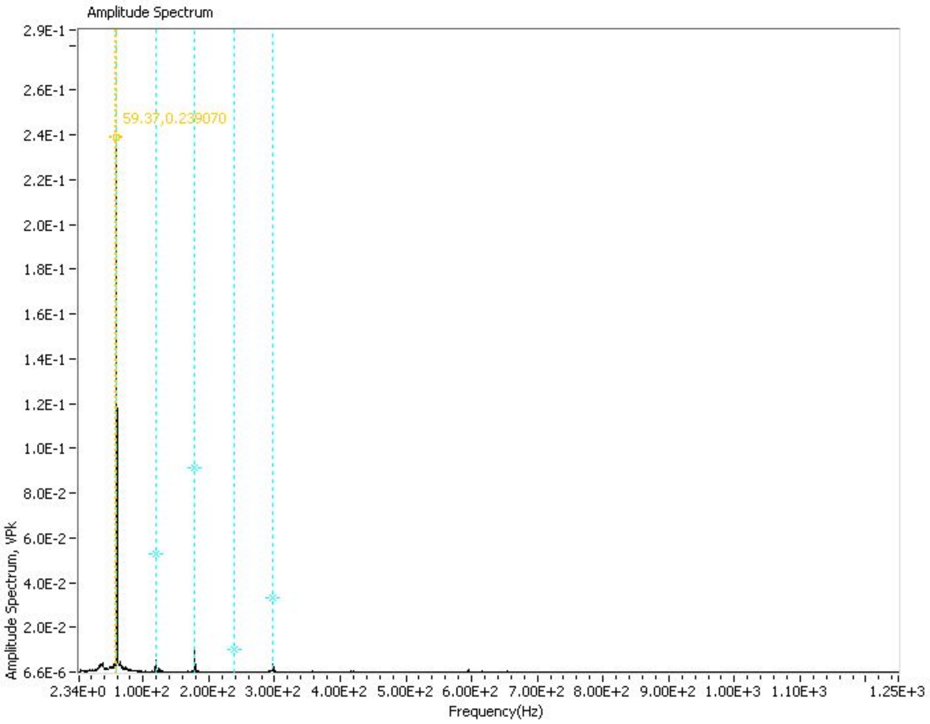


60 Hz fully developed cavitation Vibration Horizontal

Typical Data – Direct Drive 60Hz Force Comparison



60 Hz Baseline Force Horizontal



60 Hz fully developed cavitation Force Horizontal

Conclusions

- Based on the vibration data, it is hard to see a unique signature associated with cavitation.
- Force seems not to be affected by the cavitation.
- Pressure seems to be a better indicator of cavitation – more correlated.
- Motor current and noise do not changed much with cavitation.
- Cavitation might excite high frequency structural resonances.
- Vibration appears to increase with the initiation of cavitation.
- The centrifugal pump has higher vibration amplitude in the axial direction than in the radial direction.
- More work needs to be done to determine the unique signature of cavitation.

THANKS

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