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Containment Accident Pressure Committee

Task 6 – $NPSH_R$ Test Instrument Inaccuracy Effect on Published Results (CVDS Pump)

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Executive Summary

This BWROG Technical Product provides an evaluation of the potential effects of the inaccuracies of vendor test instruments on the results of factory $NPSH_R$ testing. The evaluation is based on the Sulzer CVDS model pump used at the Monticello station and at other BWR stations.

Implementation Recommendations

This product is intended for use to address (in part) issues raised in the NRC Guidance Document for the Use of Containment Accident Pressure in Reactor Safety Analysis (ADAMS Accession No. ML102110167). Implementation will be part of the BWROG guidelines on the use of Containment Accident Pressure credit for ECCS pump NPSH analyses.

Benefits to Site

This product provides a technical response to the NRC questions about the potential uncertainty in published $NPSH_R$ test results that originate from the inaccuracies of test instruments used during factory testing.

SULZER

QUALITY LEVEL

- ☐ Direct
- ☐ Indirect

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Sulzer Pumps (US) Inc.
Monticello - 12x14x14.5 CVDS RHR Pump

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CUSTOMER APPROVAL REQUIREMENT

☐ Yes ☐ No ☑ Information Only

CERTIFIED AS A VALID SULZER PUMPS (US) INC. DOCUMENT

☐ For Outside Vendor

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CERTIFICATION (when applicable)

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1.0 PURPOSE

To evaluate the impact of test instrument accuracy and test variables on the NPSHr curves published for the Monticello RHR pumps. During a LOCA event, RHR pumps of the Emergency Core Cooling System (ECCS) work under a reduced NPSH. This minimum required NPSH (or NPSHr) is a characteristic of a pump and it is determined by testing the pump under reduced suction head. Instruments used for testing pumps and obtaining NPSHr have an inherent measurement uncertainty. This report analyzes the impact of all these test instrument uncertainties and variables on the published NPSHr values.

2.0 BACKGROUND

NPSHr for a pump is defined in the industry as the suction head at which cavitation impacts the head performance leading to a three percent loss in head at a given flow and pump speed. A general test loop setup is shown in Figure 1 below.

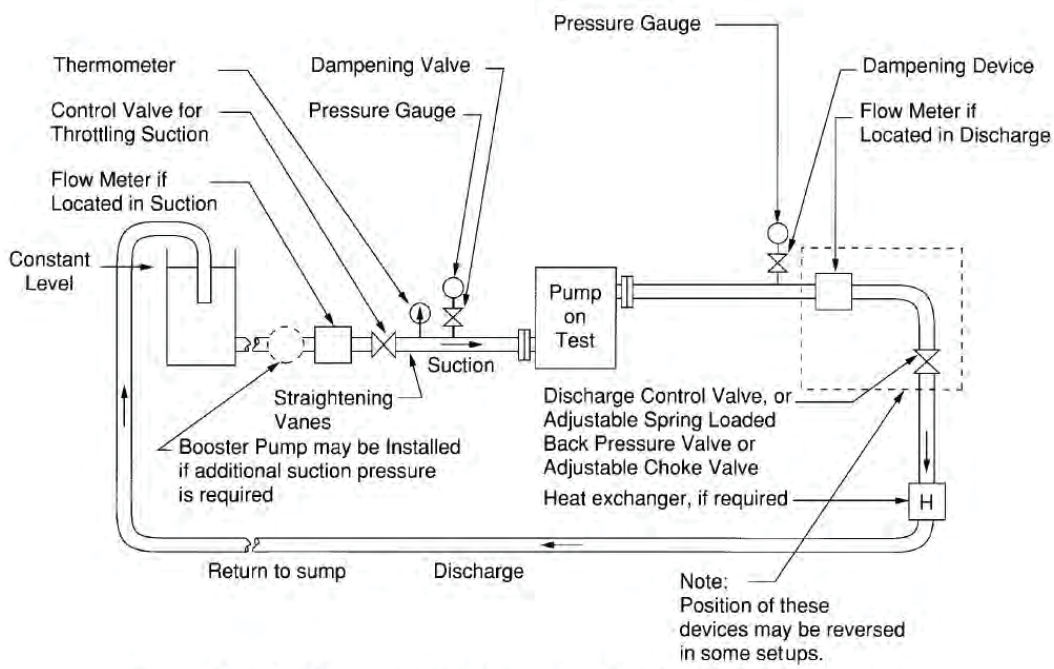

Figure 1.119 — Suppression type NPSH test with constant level sump

Figure 1: General Test Loop

During an NPSHr test, the pump is run at a constant flow and speed with the suction head reduced gradually to the point where cavitation and head loss are observed. Figure 2 below, from Hydraulic Institute's Centrifugal Pump Test Standards, shows sample NPSHr test curve results for different flow rates. These curves show the 3% head loss determination method. These curves are also known as NPSH knees.

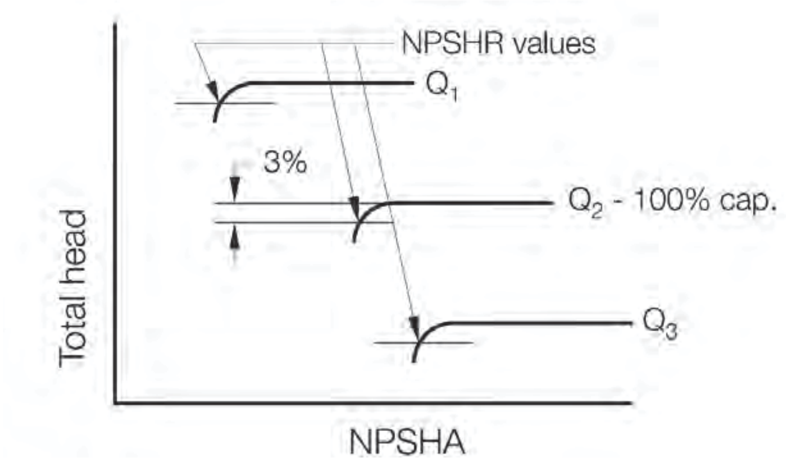

Figure 2: NPSHr Test Results, Hydraulic Institute Standards Copyright © 1997-2009

3.0 SCOPE

Monticello 12x14x14.5 CVDS RHR pumps were tested in 1969 and the test curves were generated in compliance with the industry standards that existed at that time. Measurement techniques and instruments used for developing the original Monticello NPSHr curves are no longer used in the industry. However, the basic equations for calculating suction head and plotting the curves remain the same. The following factors will be considered for evaluating the overall impact of instrument uncertainties on the NPSHr curves.

a) Instrumentation Uncertainty – Measurement uncertainty of all the test equipment used during NPSHr testing is evaluated. Test instruments include –

- Barometer – For atmospheric pressure.
- Pressure gauges (with dead weight calibrator) - Suction and discharge pressures.
- Thermocouple – Suction inlet temperature for vapor pressure.
- Venturi tubes – Flow rate.

- Stroboscope – Shaft speed.
- Micrometer – Suction inlet pipe ID and pressure instrument elevation from the fixed datum.

b) Uncertainty in NPSH (suction head) calculation using the test uncertainty calculation method outlined in ASME PTC 19.1-2005.

$$\boxed{NPSH = H_{atm} + H_{suction} + H_{velocity} - H_{vapor} \pm H_{elevation}} \quad \text{---> Eq 1.}$$

Where,

H_{atm} = Head due to atmosphere at a given location.
$H_{suction}$ = Head observed in the suction line gauge.
$H_{velocity}$ = Head due to the velocity of the pumpage.
H_{vapor} = Head due to the vapor pressure of the pumpage at the given temperature.
$H_{elevation}$ = Head due to elevation of the measurement gauges from the datum point.

In the above equation, $H_{velocity} = V^2 / 2g$, where V is the flow velocity obtained from the flow rate and the suction inlet cross sectional area.

c) Other test factors not included in the equation above –

- Pump speed
- Discharge head measurement

4.0 ANALYSIS

Much of the test instrumentation used for testing the Monticello RHR pumps is no longer the industry standard, e.g., stroboscopes have been replaced by digital tachometers, Venturi tubes by MagFlow meters, pressure gauges by transducers and thermocouples by high precision RTDs. Measurement uncertainties for these old instruments were obtained from ASME centrifugal pump test data and calibration documents. Following is a list of the instruments and their expected uncertainties at the measured value.

Table 1: Instrument Uncertainty

Instrument	Measure	Units	Accuracy (±)
Barometer	H_{atm}	mmHG	[[
Suction Pressure Gauge	$H_{suction}$	psi	
Discharge Pressure Gauge	$H_{discharge}$	psi	
Thermocouple (Type J)	H_{vapor}	°C	
Venturi Tubes	$H_{velocity}$	gpm	
Stroboscope	Speed	rpm	
Micrometer	$H_{elevation}$& $H_{velocity}$	in	]]

Suction head is the total head that the pump impeller experiences at its inlet, which is the available NPSH. An NPSHr test curve is a discharge head versus suction head curve (see Figure 2). Uncertainties in measuring the suction head will lead to inaccuracies in the NPSHr curves.

The test instrumentation uncertainty provided in Table 1 is used for predicting overall NPSH (suction head) uncertainty for the Monticello RHR pump at the flow rate of [[ ]], and [[ ]] as shown below.

$$NPSH = H_{atm} + H_{suction} + H_{velocity} - H_{vapor} \pm H_{elevation}$$

Where,

- Velocity head ($H_{velocity}$) of [[ ]] is calculated at a flow rate of [[ ]] and a suction piping internal diameter of [[ ]] using equation, $H_{velocity} = V^2 / 2g$ (see Table 2).
- H_{vapor} of [[ ]] at [[ ]] water is obtained from the vapor pressure charts.
- $H_{elevation}$ of [[ ]] is estimated for the purpose of this calculation.
- Standard H_{atm} of [[ ]] is used.
- $H_{suction}$ of [[ ]]is assumed.

4.1 Uncertainty in NPSH using ASME PTC 19.1-2005 Test Uncertainty Method

ASME PTC 19.1-2005 [1] outlines a method for determining uncertainties in results obtained using centrifugal pump test data. According to ASME PTC 19.1-2005, uncertainty in test results is a combination of systematic errors and random errors. Systematic errors are errors due to imperfect calibration corrections, measurement methods, data reduction techniques, etc, which combine to equal instrument inaccuracy provided in Table 1. Random errors are due to uncontrolled test conditions, and non repeatability in the measurement system, measurement methods, etc. An accepted practice for this method of uncertainty determination uses 95% confidence levels in the analysis. Equations and methods used below for NPSH uncertainty determination are referenced in ASME PTC 19.1-2005.

The NPSH equation above consists of several parameters. Each parameter impacts the NPSH measurement with varying amounts; this is known as parameter sensitivity. Sensitivity is also defined as the instantaneous rate of change in NPSH to a change in parameter. Sensitivity coefficient of each parameter is calculated and documented in Table 2 below.

Table 2: NPSH Sensitivity Analysis

Independent Parameter (α)	*Parameter Nominal value (α)*	*Units*	*Sensitivity Coefficient (Φ = δNpsh/δα)*
H_{atm}	[[	mmHg	[[
$H_{suction}$		psi	
Temperature		°C	
Suction Pipe ID		in	
Flow		gpm	
$H_{elevation}$	]]	ft	]]

Table 2 shows that the sensitivity of suction pressure measurement of [[ ]] is high compared to the rest of the parameters. In other words, suction pressure uncertainty can impact the NPSH results considerably.

As mentioned earlier, NPSH uncertainty is a combination of systematic and random uncertainties. Overall uncertainty, U_{ADD}, for a 95% confidence is calculated using the following equation.

$$U_{ADD} = \left[(B_{npsh})^2 + (t_{95} x S_{npsh})^2\right]^{0.5} \quad \rightarrow \text{Equation 2}$$

where,

B_{npsh} = Systematic uncertainty of NPSH – also called bias

S_{npsh} = Random uncertainty of NPSH – also called precision

t_{95} = t distribution based on number of samples, assumed 4.303 for 3 samples.

Systematic uncertainty is calculated as follows:

$$B_{npsh} = \left[(\Phi_{atm} \times B_{atm})^2 + (\Phi_{suction} \times B_{suction})^2 \ldots\ldots\ldots\ldots\right]^{1/2} \quad \rightarrow \text{Equation 3}$$

Systematic uncertainty for each parameter is calculated and listed in Table 3. Bias is calculated using the instrument inaccuracy values provided earlier in Table 1 and the nominal parameter values listed below.

Table 3: Systematic Uncertainty

Independent Parameter	*Parameter Nominal value*	*Bias (±)*	*Systematic Uncertainty = (Φ x Bias)²*
H_{atm}	[[		
$H_{suction}$			
Temperature			
Suction Pipe ID			
Flow			
$H_{elevation}$			
B_{npsh}			]]

Random uncertainty for each parameter is generally obtained by taking several measurements at the same point and studying the scatter in the results. Since for this analysis only one measurement per parameter is available, a random uncertainty equal to systematic uncertainty has been assumed. In other terms, bias used in systematic uncertainty is equal to the precision value in the random uncertainty analysis below. Random uncertainty is calculated and listed in Table 4 below.

$$S_{npsh} = \left[(\Phi_{atm} \times S_{atm})^2 + (\Phi_{suction} \times S_{suction})^2 .... \right]^{1/2}$$ → Equation 4

Table 4:Random Uncertainty

Independent Parameter	*Parameter Nominal value*	*Precision (±)*	*Random Uncertainty = (Φ x Precision)²*
H_{atm}	[[		
$H_{suction}$			
Temperature			
Suction Pipe ID			
Flow			
$H_{elevation}$			
S_{npsh}			]]

If we input the above values in the 95% confidence level equation;

$U_{ADD} = \left[(B_{npsh})^2 + (4.3xS_{npsh})^2\right]^{0.5}$, we obtain [[ ]]. Therefore, the uncertainty in NPSH obtained is [[ ]] at [[ ]].

4.2 Other Test Factors

Since NPSHr curves are generated by using the drop (3%) in the discharge head, it is important to analyze the uncertainties in the discharge head measurement as well. Just like the suction pressure, discharge head is measured using the dead weight calibrated pressure gauges. The overall accuracy of these gauges is approximated to be [[ ]]. Therefore, discharge pressure measurement variations at [[ ]] (head at [[ ]] and [[ ]]) would be approximately [[ ]].

Another factor that could lead to uncertainty in NSPHr curves is the pump speed measured using a stroboscope. NPSHr characteristics of a pump change with speed, therefore, for the purpose of consistency it is important that the pump performance (head, flow and NPSHr) be corrected to a common speed. Stroboscopes with an accuracy of [[ ]] at [[ ]] would provide a speed ranging between [[ ]].

5.0 RESULTS AND CONCLUSION

Determination of the test uncertainty shows that the total amount of variation of the suction head and discharge head measurement is approximately [[ ]]. Based on the analysis performed herein, the uncertainty in NPSH obtained due to instrument inaccuracy is [[ ]] [[ ]]. Pump speed measurement uncertainty using a stroboscope is a negligible [[ ]]. Measurement uncertainty due to instrumentation (systematic error) is small compared to the random uncertainty as observed in Equation 2. Figure 3 below shows the original $NPSHr_{3\%}$ curve along with the instrument uncertainty over the flow range.

It is important to note that the Sulzer Pumps uses industry standards described in this report for performing NPSH and performance tests on a large number of the newly manufactured pumps. There is a sizable collection of test data acquired over the years that verifies and validates the test instrument accuracy, and data collection and analysis techniques provided in this report.

[[

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Figure 3: NPSHr Uncertainty Range

6.0 BIBLIOGRAPHY

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