BWROG-TP-12-011
Revision 0
August 2012

Containment Accident Pressure Committee

Task 2 - Equation for Pump Speed Correction (CVDS Pump)

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Executive Summary

This BWROG Technical Product provides a technical evaluation of the applicability of a standard equation to the Sulzer CVDS pump model used at the Monticello station and other BWR stations. The equation correlates changes in pump speed to changes in pump $NPSH_R$.

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 concerns raised in the reference above regarding the potential for changes in $NPSH_R$ as pump operating speed is changed.

SULZER

QUALITY LEVEL

- ☐ Direct
- ☐ Indirect

SULZER PUMPS (US) INC. DOCUMENT

DOC. NO: E12.5.1910

ORDER NO: 100072780

TITLE: Task 2 – Equation for Pump Speed Correction
Sulzer Pumps (US) Inc.
Monticello - RHR & CS Pumps

ASME CODE SECTION

CLASS NO.

CODE EDITION (YEAR)

SEASON YEAR

CUSTOMER: GE-HITACHI Nuclear Energy Americas LLC

PROJECT: Monticello Nuclear Power Station, Monticello, MN

CUSTOMER P.O. NO. 437054820

CONTRACT NUMBER

SPECIFICATION NO.

ITEM / TAG NUMBER

CUSTOMER APPROVAL NUMBER:

SPACE FOR CUSTOMER APPROVAL STAMP
(when applicable/available)

CUSTOMER APPROVAL REQUIREMENT

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Originating Dept: Advance Engineering

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Date: 11/7/2011

APPLICABLE S.O. NUMBERS:
0

DOCUMENT IDENTIFICATION	Rev.
E12.5.1910	0

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1.0 PURPOSE

To evaluate the use of the equation provided in standard HI/ANSI 1.6 2000 [1] for predicting NPSHr at different pump speeds. More specifically, this analysis is being performed for RHR and CS pumps installed in the Monticello nuclear facility. These pumps, when tested at the Sulzer Pumps factory, were operated at a fixed speed using electrical induction motors. Test motors have a slip factor that is dependent upon motor design (efficiency and motor power ratings) and applied load. In the nuclear facility, operation at less than full-rated motor power or with high-efficiency motor tends to reduce motor slip, which can cause the pump to operate at slightly higher speeds in the field compared to factory test speed. In addition, an increase in the frequency of the motor power source may result in pumps running at higher speeds than the tested pump thus increasing the required NPSH.

2.0 BACKGROUND

The physical process of cavitation (boiling) involves a phase change. In the context of a centrifugal pump inlet the energy, or latent heat of evaporation, required to facilitate the phase change associated with cavitation must be supplied by the liquid surrounding the cavitation vapor bubbles. This heat transfer process from the supporting fluid to the vapor gives rise to important physical characteristics of the cavitation process in pumps, one of which includes temporal component. That is, it takes some finite amount of time for the heat transfer associated with the formation of cavitation bubble to take place. The implication of this in the context of a pump inlet is that the longer the residence time of the flowing fluid in the low pressure zone at the blade leading edges, the greater the bubble formation. And conversely, the shorter the residence time of the fluid in the low pressure zone the less bubble formation there will be. This explains why the exponent 2 (square law as discussed in section 3 below) overpredicts the NPSHr when scaling up in speed and why it underpredicts the NPSHr when scaling down in speed.

3.0 SCOPE

The NPSHr prediction equation for pump speed correction from HI/ANSI 1.6 standard is:

$$NPSH_2 = \left(\frac{n_2}{n_1}\right)^2 \times NPSH_1, \text{ ------- (1)}$$

Where;

$NPSH_1$ = Net positive suction head at test speed;

$NPSH_2$ = Net positive suction head at specified speed;

n_1 = Test speed in rpm;

n_2 = Operating speed in rpm;

The above equation (1) provides a square law relationship between the pump speed and NPSHr. This relationship is evaluated for speed changes encountered in the field. The range of assessment will be limited to [[ ]] of the nominal pump speed, which should bound all speed variations that could be encountered in the field. Moreover, alternative NPSHr speed correction methods are compared to equation (1) for predicting NPSHr speed dependence. These sources also provide physical reasoning for using equations derived from empirical data when predicting NPSHr at speeds lower than the test speed.

4.0 ANALYSIS

Equation (1), has been endorsed in several centrifugal pump books and papers on cavitation and has been termed as a conservative approach to NPSHr speed correction when adjusting for higher speeds because it tends to overestimate NPSHr. As an example of the application of equation (1) for increased pump speed, consider that at [[ ]], test curves for the Monticello RHR pumps show an NPSHr of [[ ]] at a test speed of [[ ]]. A [[ ]] increase in pump nominal speed equals [[ ]]. In equation (1) we substitute this speed and obtain an NPSHr of [[ ]]. This is [[ ]] higher than the test NPSHr.

For predicting NPSHr at speeds below the test speed, equation (1) tends to underestimate NPSHr. This can lead to pumps experiencing degraded performance due to cavitation if the NPSHa provided by the plant is insufficient due to an optimistic prediction of the pump NPSHr at a reduced speed. For estimating NPSHr under certain conditions (e.g. speed reduction) HI/ANSI 1.6 standard allows the use of empirical data obtained by respective pump manufacturers. Johann Gulich's book; Centrifugal Pumps [2], uses test data from eight pump manufacturers for developing an equation for lower speed NPSHr prediction.

Gulich's Equation:

$$NPSH_2 = \left(\frac{n2}{n1}\right)^x \times NPSH_1 \text{ , where x (exponent) = } 2 \times \left(\frac{NPSH_3}{NPSH_{ref}}\right)^{0.3} \text{ , ---- (2)}$$

Where, $NPSH_{ref}$ = 20 m.

If we use Gulich's equation (2) above, that is based on empirical data, to predict the NPSHr at [[ ]] we would obtain x = [[ ]] and new NPSHr as [[ ]] less than the [[ ]] predicted by equation (1). This illustrates that the use of exponent 2 (square law approach) is a conservative approach when correcting NPSHr for higher operating speeds.

5.0 RESULTS AND CONCLUSION

For speed variations of [[ ]] of the test speed, the HI/ANSI 1.6 2000 square law equation is suitable for determining changes in NPSHr for speed increases for the RHR and CS pumps. For speed decreases, an empirical correlation such as that prescribed by Gulich is recommended.

6.0 BIBLIOGRAPHY

[1]: ANSI/HI 1.6, 2000, American National Standard for Centrifugal Pump Tests

[2]: Centrifugal Pumps, Johann Gulich, 2nd Edition.

[3]: Centrifugal Pumps Book, Stepanoff.